TM 5-240

WAR DEPARTMENT TECHNICAL MANUAL

U.S. Dept. of Army

AERIAL PHOTOTOPOGRAPHY

WAR DEPARTMENT • 10 MAY 1944

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This manual supersedes TM 5-240, 21 November 1941

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WAR DEPARTMENT,
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TM 5-240, Aerial Phototopography, is published for the information and guidance of all concerned.

[A. G. 300.7 (30 Dec 43).]

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

J. A. ULIO,
Major General,
The Adjutant General.

DISTRIBUTION:

As prescribed in paragraph 9*a*, FM 21-6: Armies (5); Corps (5); D (5); R 1 (1); IBn 1 (5); IBn 5 (10); IBn 6 (5); IC 5 (5), (20).

IBn 1 (5): T/O and E 1-785, Photographic Sq; (MT), Photographic Sq., Photo. Photo Compilation; 1-759 Photo Charting Sq; 1-758, Photo Mapping Sq; (Allotment), AAFTC Photo Flight (Sep); 1-779, Photo Tech. Sq; (Allotment) Photo Rcn Sq; 1-757, Photo. Rcn. Sq; (Allotment), Absn. Trg. Sq.

IBn 5 (10): T/O and E 5-55, Engr. Topo. Bn (Army); 5-185, Engr. Top. Bn. (GHQ).
IBn 6 (5): T/O and E 6-75, F. A. Obsn. Bn.
IC 5 (20): T/O and E 5-400; Engr. Avn. Top. Co.
IC 5 (5): T/O and E 5-500; Survey Liaison Det; 5-500, Model Making Det.

For explanation of symbols see FM 21-6.

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CONTENTS

This manual supersedes TM 5–240, 21 November 1941.

SECTION I
GENERAL

1. Purpose

This manual provides information on all methods by which military organizations prepare maps from aerial photographs.

2. Scope

The following sections cover the military methods of mapping from aerial photographs and the requirements for aerial photography, for ground-established control and for preparing maps for reproduction. They do not cover the details of drafting included in TM 5–230, or the details of Multiplex operation included in TM 5–244. The glossary contained in appendix I includes definitions of terms used in this manual.

3. Responsibility

Under the provisions of AR 300–15, the Army Air Forces and the Corps of Engineers are charged jointly with preparing military maps which require the use of aerial photographs.

a. The Corps of Engineers is charged with prosecuting surveys, including photogrammetric processes and compilations, with producing or revising maps required for military purposes, and with preparing specifications and priorities for aerial photography required for mapping.

b. The Army Air Forces are charged with performing the aerial photography required for military mapping in accordance with the approved specifications and priorities recommended by the Corps of Engineers. The Army Air Forces further are responsible for procuring and compiling aeronautical charts and for the aerial photography necessary for that purpose. Since engineer organizations are sometimes called upon to compile aeronautical charts, the information required for their preparation is included in this manual with the exception of the special symbols for aerial navigation aids found only on aeronautical charts.

4. Organization

a. Staff Responsibility. The supply of maps, including photomaps and photographs, is one of the most important command responsibilities exercised by the commander through his G–2. He is responsible for the employment of topographic and photographic units assigned to the echelon, and for coordinating requests for aerial photography and maps when these units are not assigned.

b. Engineer Units. Topographic troops are provided by the Corps of Engineers for the purpose of using aerial photographs to compile maps and to reproduce and distribute them. The largest topographic organization is the engineer topographic battalion (GHQ). This organization is normally assigned to higher headquarters to carry on the mapping needed for its operations. The engineer topographic battalion (army) is a smaller unit and is mobile. This organization is usually assigned to an army to reproduce existing maps in quantity, to revise existing maps, and to perform a limited amount of new mapping. A similar, smaller organization is the engineer topographic company (corps), normally assigned to a corps. Engineer aviation topographic companies and battalions are assigned to an air force to prepare its special maps and charts.

c. Air Force Units. The Army Air Forces have several types of units to perform aerial photography. Some of these units are equipped to take photographs to be used primarily for the preparation of maps. Other air force units are concerned primarily with reconnaissance photographs for intelligence purposes. Army and GHQ topographic battalions normally work from *mapping* photography while corps topographic companies work from *reconnaissance* photography. Since reconnaissance photography is available before mapping photography in many areas, GHQ and army topographic battalions may be required to use reconnaissance photography for map preparation. G–2 of the echelon in which topographic units are operating should be contacted for information of air force units equipped to perform mapping photography.

d. Other Units. In addition to the topo-

graphic troop units described above, the Corps of Engineers may establish and operate base mapping plants under conditions favorable to such plants. These may be staffed by either civilian or military personnel. At the other extremity of organization are many units with survey equipment suitable for limited amounts of mapping. Mapping operations of these units are limited according to requirements of their special missions. Aerial photographs may be used when available.

5. Maps Required

a. Types of Maps. Military operations require various types of maps of different scales. Commanders and staffs of large units require small-scale maps of large areas to plan offensive and defensive measures and necessary communication operations. Larger scale maps are used by smaller units. To attack or defend heavily fortified areas, especially large-scale maps may be required. Such maps normally cover relatively small areas.

b. Preparation. All types of military maps may be prepared from aerial photographs. Normally, original compilation from aerial photographs is accomplished at scales larger than 1:50,000. Maps of smaller scales are usually compiled from other sources, although photographs often form the only material available for an area. Similarly, photographs are not normally used for compiling military maps of a scale larger than about 1:20,000, but sometimes may be used to advantage in preparing maps of limited areas at scales as large as 1:5,000. In preparing maps at scales of 1:100,000 or smaller, it is likely that larger scale sheets will be compiled first, and smaller scales obtained by reducing and recompiling them. Most work will be for scales between 1:20,000 and 1:100,000.

6. Methods Employed

Maps may be plotted from aerial photographs by employing stereoscopic plotting instruments or by graphical methods. The Multiplex stereoscopic instruments, suitable for preparing precise topographic maps, are normally used only in the GHQ organizations and base plants. The stereocomparagraph, suitable for the preparation of reconnaissance-type topographic maps, is the only other stereoscopic instrument in use. It is found in most topographic organizations. All organizations can use any of the graphical methods to prepare planimetric maps or map substitutes. These methods include radial-line plotting of vertical photographs, use of oblique photographs by graphical methods, and preparation of photomaps from single photographs or from mosaics.

7. Accuracy

a. The methods used for mapping a given project should be selected to produce in the most efficient manner a map having the desired accuracy. Too often emphasis is placed upon a certain method without regard to the final product desired, and the use of that method is excused on the grounds of military expediency. Such an excuse should not be used for poorly executed work. Both in training and in field operations methods should be followed that will produce a map conforming to peacetime standards. Only in this way can an organization produce such a map when required, and be able to evaluate the reliability of a map produced under adverse conditions actually resulting from military operations.

b. It is as important for an organization to know the weaknesses of a map as for it to be able to produce a map of the desired quality. Throughout this manual emphasis is placed on the employment of methods to obtain products meeting peacetime standards of quality. The effects of military operations on quality are pointed out and evaluated so that responsible personnel may decide on the best methods, and may evaluate the reliability of maps made under adverse conditions.

8. Planning

Planning will vary with the particular circumstances surrounding any project. Factors which must be considered include ground control, aerial photography, methods of compilation, drafting, reproduction, and the effect of the military situation upon all of these. Only by a thorough knowledge and understanding of all these factors can a mapping project be made to produce the desired map in the shortest possible time.

9. References

a. Army Regulations and Field Manuals. AR 300–15, which prescribes the responsible mapping agencies and the general specifications for mapping, is the basic authority for the Army's mapping activities. FM 30–20 is a further and more detailed development of these regulations. It contains in condensed form the necessary information for commanders and their staffs. FM

30–21 describes types of aerial photographs and illustrates their use both as maps and intelligence instruments. FM 21–30 prescribes the symbols to be used in preparing maps. FM 1–35 contains information concerning the employment of the air forces in obtaining aerial photographs. FM 21–25 and 21–26 contain descriptive material concerning maps and photographs and instructions for the use of these products.

b. Technical Manuals. TM 5–230 and TM 5–244 both pertain to mapping from aerial photography. The former covers the use of photographs by graphical methods as well as drafting for map work. The latter is devoted entirely to operation of the Multiplex equipment. TM 5–235 and TM 5–236 cover the material on surveying necessary for establishing control for mapping from aerial photographs.

c. Other References. Other publications relating to aerial photography, surveying, and mapping are listed in appendix II.

SECTION II

AERIAL PHOTOGRAPHY

10. Responsibility

a. ARMY AIR FORCES. The Army Air Forces are responsible for—

(1) Execution of aerial photography for mapping and charting.

(2) Processing negatives.

(3) Identification and filing of negatives.

(4) Furnishing prints and negatives required to prepare maps.

b. CORPS OF ENGINEERS. Duties of the Corps of Engineers in connection with aerial photography are—

(1) Preparing specifications and priorities for aerial photography for mapping.

(2) Indexing mapping negatives.

11. Aerial Photographs

a. An aerial photograph used for mapping is not much different from a photograph taken principally for pictorial effect, but its pictorial qualities are less important. These qualities are used only to identify the various features that appear on the photograph so that they may be shown in conventional signs on a map. This identification is readily made if the features appear on the photograph in large enough size. Identification, then, is primarily a matter of scale.

b. The characteristic of a photograph most important in mapping is perspective. Actually, the camera registers on the film a perspective projection of the objects in the field of view. This perspective is used to assemble the various objects depicted into their map positions. The lens acts as a perspective point through which rays from objects on the ground are projected on the surface of the film, as illustrated in figure 1. There is a definite relationship between the position of images on the perspective projection and the position of objects on the ground. This relationship is used to plot the map position of these images, and will be discussed more fully in section V.

12. Aerial Cameras

a. PRINCIPLE. The aerial camera is no different in principle from the common box camera, though for mechanical reasons it is much more complicated. It consists of a lighttight box which supports the lens and shutter at one end and the light-sensitive film at the opposite end. Like the box camera, the aerial camera is of the fixed-focus type, with the lens fixed at a predetermined distance from the film for best focus. This setting is possible since all objects photographed from the air are at distances so great that they may be considered to be at infinity. Through its lens, the camera registers a perspective projection on the plane of the light-sensitive surface of the film. For easy operation, there are devices for actuating the shutter and diaphragm mechanisms and for winding the film between exposures. A typical aerial camera is shown in figure 2, and a diagram of its essential parts in figure 3.

b. TYPES. The Army Air Forces have a number of different types of cameras designed for different purposes, such as mapping, intelligence, day reconnaissance, night reconnaissance, and orientation. Focal lengths of lenses used in these cameras vary from 6 to 40 inches.

(1) The T–5 camera, illustrated in figure 4, is used for tactical mapping by the Corps of Engineers. This camera is equipped with a 6-inch, wide-angle lens, and exposes a negative area 9 by 9 inches. In addition, there is exposed simultaneously with each negative a strip of data consisting of the recording of an altimeter, level bubble, clock, data card, and counter. These data record conditions at the instant of exposure, and are useful in some mapping methods. This camera has all the requirements needed for precise topographic mapping and should be used for this purpose, especially when Multiplex mapping is contemplated.

(2) Another camera satisfactory for all mapping purposes is the K–17 with a 6-inch focal length cone. Lacking the extreme precision of the T–5 camera, it has the same lens and negative area. This camera is similar to that illustrated in figure 2, which shows a K–17 camera having a 12-inch focal length cone.

(3) Other types of cameras designed for recon-

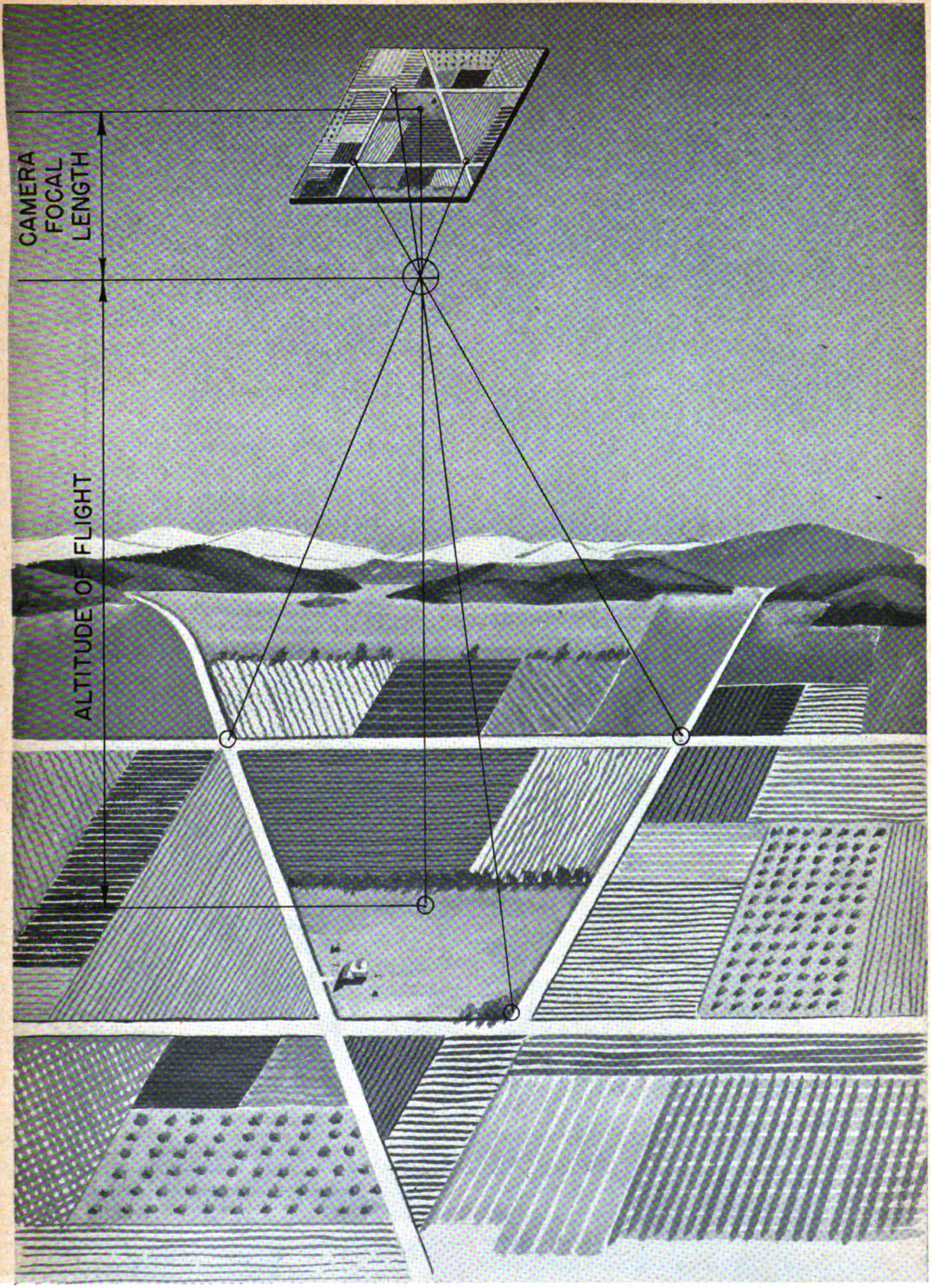


Figure 1. Action of camera lens.

Figure 2. Typical aerial camera.

naissance and intelligence photography and having other focal lengths, may also be used in mapping operations. Most of these cameras, including the T–5 and K–17, use 9½-inch-wide roll film and expose a negative area 9 by 9 inches, although a few cameras make exposures of different size. In addition to these cameras, cameras of allied nations may be used occasionally for mapping purposes.

c. LENS. The lens is the most important part of any camera, since it forms the images on the sensitized film. In general, all Army Air Forces day-reconnaissance type cameras have lenses satisfactory for all mapping methods except Multiplex. Since Multiplex equipment is designed around certain types of lenses, only cameras having these lenses can be used. Cameras used for Multiplex mapping are discussed more fully in section X and in TM 5–244.

d. SHUTTERS. (1) Most Army Air Forces cameras employ a shutter mounted between the elements of the lens. This shutter consists of thin metal leaves so arranged that they may separate almost instantaneously to let the light pass through the lens, may remain open for a definite fraction of a second, and may then close almost instantaneously, all this action being controlled by the mechanics of the shutter. This action permits exposure of all parts of the negative at the same time and in so short an interval that the motion of the camera through the air during exposure is negligible. This type of shutter is used for precise mapping work.

(2) Another type of shutter used on some cameras is the focal-plane shutter. In this, exposure is made by a slit in an opaque curtain being pulled rapidly across the width of the film immediately in front of the film or focal plane. This action permits light, which is always passing through the lens, to strike the film only during the time it takes the slit to pass any given point on the film. This time is so short at any one point that motion of the camera through the air does not produce any noticeable visual effect. The time required for the slit to pass across the *entire* negative, however, is not always negligible and results in one side of the exposure being made from a different point in the air than the other side. Thus, no single perspective is recorded on the film, and the resulting photograph is unsuitable for accurate mapping.

(3) The amount of distortion which a focal-plane shutter produces in perspective depends upon the flight altitude and the time required for the slit to pass across the film. For high-altitude photography with a fast focal-plane shutter, distortion of perspective is extremely small. Photographs taken with a focal-plane shutter are for photomaps, but should be avoided, if possible, when graphical methods or the stereocomparagraph are used, and should never be used when the Multiplex method is employed.

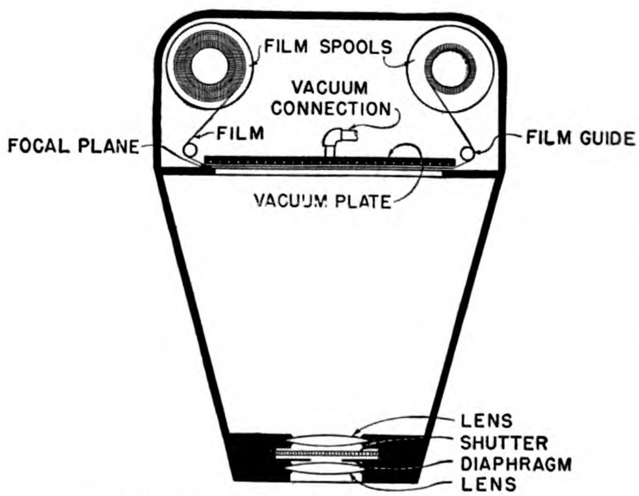


Figure 3. Schematic diagram of aerial camera.

e. Flattening of Film. Most Army Air Forces cameras employ a vacuum to keep the film flat in the focal plane during exposure, so that the perspective projection is recorded on a plane. In the vacuum-back camera, this flattening is done by a flat metal plate behind the film which presses it against the focal-plane frame. This frame has an opening the size of the exposure, and locates the film at the proper distance from the lens. A vacuum applied through grooves in the metal plate pulls the film flat against the plate during exposure. A few types of camera keep the film flat simply by having a metal plate press the film against a glass plate mounted in the focal plane of the camera body. Although this glass plate somewhat affects the perspective registered on the film, the distortion is not large enough to affect the use of such photographs in preparing photomaps or for maps prepared by reconnaissance methods. However, glass-plate cameras are not used for precision mapping.

f. Fiducial Marks. The principal point of a photograph is important in practically all mapping operations. Hence, all aerial cameras which may be used for mapping have distinctive metal tabs or indentations at the four sides of the focal-plane frame. These are called fiducial marks, and are located so precisely that the intersection of lines joining opposite sets of fiducial marks indicate the principal point of the photograph accurately enough for all mapping purposes.

13. Mounting of Aerial Cameras

a. Types. Aerial cameras are mounted in aircraft in two different ways. The older, more usual, and more desirable mounting for mapping photography is the adjustable type. A more recent type, more desirable for tactical employment in military operations, is the fixed mounting.

b. Adjustable Mounts. In adjustable mounting, the camera is suspended in a mount which may be rotated around three mutually perpendicular axes. The lens points vertically downward over an opening in the bottom of the aircraft. The camera may be tilted about so that its axis is vertical at the instant of exposure, and may be rotated about a vertical axis so that the sides of its exposure frame are parallel to the track of the aircraft over the ground. These adjustments for tilt and drift of the aircraft may be made manually or by mechanisms controlled from some other part of the aircraft. These adjustable features compensate for changes in tilt and for drift caused by cross winds. The tilt is usually determined by reference to a level bubble mounted on the camera or on the control mechanisms. A view finder or drift sight is used to determine the angle between the axis of the aircraft and its track over the ground.

c. Fixed Mounts. In the fixed type of mounting, aerial cameras are secured rigidly to the frame of the aircraft in such positions that they point

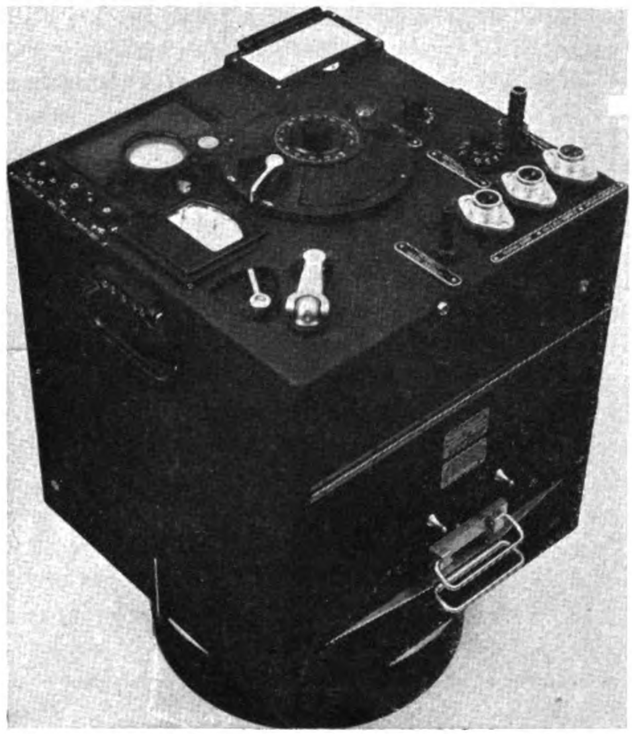


Figure 4. T–5 camera.

out through openings provided. They may be mounted to point vertically downward or to either side, forward, or aft at some considerable tilt from the vertical. Several cameras pointing in different directions may be mounted in this manner and may be used either with or without a camera mounted in the adjustable type mount. The more usual type of fixed mount places the cameras in a position to cover an area vertically below, or a band or area extending in a direction normal to the axis of the aircraft. When more than one camera is used to cover such a band of area they are interconnected electrically so as to make exposures simultaneously.

d. Airplane Types. Aerial cameras may be mounted in any type of airplane in which space is available for the camera and its accessories, in a position where the camera may be pointed in the

desired direction. Almost invariably, the fixed type of mounting is used when cameras are installed in fighter type or single-seat airplanes. In larger airplanes, either the fixed or adjustable type mounting may be used. In some installations both types are used.

e. INTERVALOMETERS. Practically all Army Air Forces cameras are electrically operated. An electric motor winds the film and shutter, and an intervalometer trips the shutter at the proper time. The intervalometer controls the exposure cycle at an interval set and determined by the operator using a view finder. On the ground glass of the view finder, the operator can actually determine the speed of the plane with reference to the ground and, hence, can determine at what interval exposures should be made. Where there is an operator with the camera, the view finder and the intervalometer are mounted convenient to him. In fixed or remote-control mountings, these accessories are mounted convenient to the pilot or to the remote-control station.

f. PREFERRED TYPE. Photography with adjustable camera mountings is the desirable type for mapping purposes. With such a mounting, and with proper orientation, the tilt of the camera is more uniform. Since the flying altitude of an airplane varies, it is not possible to fix a camera in a mount and secure uniform tilts. The variation of the level of the airplane from moment to moment around its normal position is of an accidental nature and can be compensated to some extent by an operator using the adjustable type mount. With the fixed type mount, accidental variations in tilt are likely to be larger.

14. Photographic Coverage

a. FORWARD LAP. (1) Given the camera and flight altitude to be used, the objective of all methods of mapping photography is to cover a required area with the smallest number of overlapping photographs consistent with variables present in flying. For a given area, this objective is usually accomplished by flying along straight and parallel lines spaced over the area, exposing photographs along these lines so as to secure the proper overlap. To be useful in mapping, it is necessary that each vertical or nearly vertical photograph be so exposed as to cover more than 50 percent of the same area covered by the preceding exposure of the same flight. The one exception to this requirement is in photography for the preparation of uncontrolled photomaps. Even then an overlap of more than 50 percent is desirable. To keep the forward lap between 55 and 65 percent, which is the desirable range, it is usually planned to obtain 60 percent forward lap.

(2) The spacing of exposures for the desired forward lap is determined by use of the view finder, as noted previously. In fighter type installations, where the view finder cannot be used readily, the exposure interval is based on the indicated flight altitude and on an estimate of the airplane's speed with respect to the ground. Since both these factors are subject to errors of determination, the resulting exposure interval may be far from that desired. When combined vertical and oblique cameras are used, or when two cameras are mounted obliquely to each side of the vertical to cover by simultaneous exposures a band of area normal to the axis of the airplane, the exposure interval is so arranged as to obtain 60 percent forward lap of the consecutive verticals of the flight or the area vertically beneath the airplane.

b. SIDE LAP. The spacing between parallel flight lines is arranged so that all the area between flights is covered by overlapping exposures made on one or both flights. It is desirable to have the greatest possible spacing between flights, so as to reduce to a minimum the amount of flying and photography; but the actual spacing must be arranged with due consideration for other factors. Most important of these factors is the ability of the pilot to fly over the planed lines. Flights are usually spaced to provide from 30 to 40 percent side lap, in order to assure complete coverage of an area. However, this percentage varies according to conditions. In determining the percent of side lap to be used, consideration must be given to the area's relief. As the flights vary from the desired lines, the side lap also varies, but the objective of complete coverage is met if a small amount of side lap is maintained.

c. ALTITUDE. Since the area covered by a given camera increases as the square of the flight altitude, and since the width covered across the flight increases in proportion to the flight altitude, it is desirable to photograph from as high an altitude as possible. At higher altitudes a wider flight spacing may be used, and fewer photographs and less flying are required for a given area. The flight altitude used for mapping photography is actually selected, however, with additional consideration for the accuracy desired in the map, the

amount of detail necessary to be identified, and the type of camera to be used. If photography is contemplated over enemy territory, consideration must also be given to the amount of hostile opposition. This, if present, will tend to force aircraft to higher altitudes. Once determined, altitude is maintained as nearly constant as possible during the course of photography. Under best conditions, altitude will not vary over a range of more than 100 feet during the course of any flight.

d. Tilt. Tilt in a vertical aerial photograph and tilt other than that established by the mounting of an oblique installation have the effect of reducing the amount of sidelap on one side of the flight line and increasing it on the other. Thus, if the amount of sidelap is barely sufficient on vertical photographs, it will become insufficient on one side if there is tilt. The effects of excessive tilts are discussed under each method of mapping. The cameraman controls tilt when the camera is mounted in an adjustable type mount, but the level bubble which he uses as an indication of vertical is affected by all the accelerations of the aircraft. Hence, the pilot plays a large part in obtaining tiltless photography by holding the aircraft level. When an adjustable type mounting is used under the most favorable flying conditions, the average tilt of a vertical photograph should not exceed 2°, and the maximum tilt should not exceed 5°. With fixed mountings, the pilot alone levels the mounting by controlling the level of the airplane. When photographs are taken over terrain where the enemy is active, greater tilts will probably have to be acceptable.

15. Time of Photography

a. Weather. One of the prime requisites in aerial photography is a practically cloudless sky below the altitude of photography. In some localities skies are clear only at certain times of the day, while in other locations skies are clear only at certain seasons of the year. Aerial photography must be planned to take advantage of every available hour of cloudless skies with due regard to other factors, such as the time of day pictures should be made and the time available.

b. Altitude of Sun. The minimum altitude at which the sun will give enough light for mapping photography varies with the type of terrain. For flat terrain the sun should be more than 20° above the horizon. As the relief increases and as the ground slopes become steeper, the sun must be higher so that the areas sloping away from the sun will still be lighted well enough to record the necessary detail on the exposures. Features cannot be mapped unless they appear on the photograph. For mountainous terrain the sun should be 40° to 45° above the horizon. The time of day when the sun is above the minimum desired altitude varies with the latitude of the locality and the season of the year.

c. Ground Cover. Because cover of foliage, snow, or water often hinders the recognition of topographic and planimetric detail, photogrammetrical methods are best conducted if photography is done when such covers do not exist. When aerial photography is needed immediately operations cannot wait for best ground conditions, but in long-range planning this phase can be considered.

16. Photographic Materials

a. General. Most of the usual photographic materials and methods are suitable for preparing negatives and prints for mapping. For some uses, however, care is necessary in selecting materials and methods.

b. Film. For photographs to use in stereoscopic mapping, or for mapping methods where precise measurements on photographs are necessary, only topographic-base aerial film should be used. Since this film has the highest possible dimensional stability, the perspective recorded in the camera will remain undistorted on the film through processing and subsequent atmospheric changes. This film is marked at frequent intervals along the edges of the roll to indicate that it is on a topographic base, and can be identified in that manner. The marking is apparent on the developed film and on prints which include the edges of the film. However, to remain undistorted it must not be stretched or pulled by the equipment used in the processing operations.

c. Paper. Common double-weight photographic paper has fair dimensional characteristics. Some differential shrinkage usually takes place in this paper between its exposure on a printer and its final dry form after processing. After drying, some differential shinkage will also be found, resulting from atmospheric changes. These changes are fairly small and have only minor effect on the use of double-weight prints for reconnaissance methods or for preparation of photomaps. For best results, however, this paper must be allowed

to dry naturally in circulating room air and must not be placed in mechanical print dryers or print straighteners. Waterproof paper has good dimensional characteristics and is satisfactory for mapping.

17. Quality

The importance of quality in both aerial photography and its resulting products cannot be overemphasized. Photographic quality has great effect on all later operations in mapping procedure, regardless of the method used. No effort within reason should be spared to obtain the best, because photography can immensely influence the time and accuracy of the resultant mapping. Photography should be planned as far as possible in advance so that bad flying conditions will not necessitate acceptance of lower quality photography. Good photography will immeasurably speed the preparation of desired maps. It must be remembered that time of completion of the *whole* mapping operation is the governing item in most projects.

18. Requirements for Mapping

a. IDEAL REQUIREMENTS. Briefly, the ideal requirements for mapping photography are that the area to be mapped be covered completely with the smallest possible number of properly overlapping photographs, exposed in a suitable mapping camera from the best constant altitude for the accuracy required, and exposed without tilt or, in the case of oblique photography, with a constant tilt. It is obvious that all these requirements cannot be filled completely, especially against enemy opposition, but they should be kept in mind at all times, and every effort made to attain them. Some tolerances must be allowed. The desired tolerances are more rigid for some requirements than for others, and may be greater for one type of mapping than for another. In general, it is desirable to strive to meet higher requirements so that the use of resulting photography need not be restricted to a given type of mapping.

b. CAMERA. The most desirable characteristics of the camera used for mapping photography are that it cover the widest possible area and produce a photograph the scale of which is sufficiently large for the accuracy desired in identifying and plotting the features on the ground. It is possible to plot to the usually desired accuracy at scales smaller than those which will give enough clarity for identification purposes. This can be overcome by employing two or more cameras. The widest coverage is found in cameras of short focal length, and these are best used for the actual mapping operations. If, in addition to the short-focal-length, wide-angle camera, a longer focal-length camera is also provided, the photographs from that camera may be used for identifying features to be mapped. As the longer focal-length cameras usually cover less area, two or more may be mounted to cover the same width across the flight that the wide-angle camera covers. The installation of two or more longer focal-length cameras involves oblique photography, but this photography is normally used for interpretation only.

19. Planning Photography

a. AREA TO BE PHOTOGRAPHED. Several factors operate to influence the area to be photographed for a particular mapping project. The area desired to be mapped is, of course, the basic factor. Its size and shape may be based on several requirements. The area may be determined by necessities of military planning and operations, political boundaries, geographical boundaries, terrain or water features, or arbitrary boundaries such as latitude and longitude. In any event, this area is usually predetermined for the organizations involved in mapping and aerial photography.

b. FACTORS TO BE CONSIDERED. The plan for photography should be determined with due consideration of other factors, such as the shape of the area to be mapped, the existence of large water areas, the location of existing ground control, the character of the terrain as it affects ease of locating additional required ground control, and the place of the project in any larger mapping program or possible expansion of the existing program. All these factors will bear close study, since the proper planning of the area to be photographed can save many dislocations as the mapping progresses into later phases. Photography is the foundation upon which the map is built, and it is much simpler and easier to lay that foundation squarely at the start than to go back to square it after part of the structure has been built above it.

20. Flight Maps

a. MAP TO BE USED. Submitted with the specifications is a map outlining the area to be photographed. It should be the best available map of the area, because it is generally used by the photographic crew executing the mission. However, the

best available map is usually not altogether dependable, since mapping is undertaken where existing maps are poor. The most desirable map for flying is one of a scale that shows the location of flight lines spaced at 1- to 2-inch intervals, is easily read under adverse conditions, has an accuracy of planimetric position consistent with the requirements for placing of flights, shows those terrain and cultural features which are easily recognized from the air, and is not burdened with excessive detail of no value to the photographic crew.

These requirements are best met by a mosaic or photomap, since these present a picture of the ground that nearly coincides with that seen from the air. However, the scale of a photomap is usually too large to be used conveniently in the restricted space of an airplane, and the photomaps are seldom available for an area to be mapped. Where existing maps are so poor as to be useless for flight maps, it is sometimes advisable to photograph the area with a wide-coverage camera from as high an altitude as possible, solely to provide a better flight map for mapping photography. In some cases it may be desirable to redraft a map so as to eliminate confusing material and to emphasize the more important features. No effort should be spared to obtain the best possible map to use in photographing any area, since it is an important adjunct to obtaining the best quality of flying. Even with the most improved instrumental aids for precision flying, reference must be made to maps for the desired placing of flight lines.

b. PREPARATION. Placing the flight lines on the map is normally done by the air force unit which is to perform the photography. These lines are placed on the map heavily enough to be easily legible, but not so heavily that pertinent detail beneath the line cannot be read. The spacing of the flight lines on the map is a function of the focal length of the camera, the altitude above the average elevation of the terrain, the width of the photograph, the percentage of side lap desired, and the scale of the flight map. This spacing is given by the following formula:

$$S=\frac{12AW(1-P)}{fd}$$

Where: S=Spacing between flight lines, in inches

W=Width of photo in inches

A=Altitude in feet above average elevation of terrain

P=Percent side lap as decimal fraction

f=Focal length of camera, in inches

d=Denominator of representative fraction scale of flight map.

Where there is considerable relief, its effect on flight-line spacing must be considered. An abrupt and considerable change of ground elevation may so change the scale of the resulting photography as to cause insufficient side lap.

21. Flight Direction.

a. CONSIDERATION OF CONTROL. (1) The best direction for making flights for mapping photography should be determined only after due consideration of several factors. The principal factor is the location of existing ground control in the area, and the ease of establishing the additional control required. Since obtaining ground control takes longer than any other item in preparation of a map, all efforts should be directed toward reducing the work to a minimum consistent with the accuracy required. Since the requirements for spacing control are usually such that control must be placed at intervals along strips of photographs, the most economical layout of control is with traverse lines lying generally normal to the flight lines.

(2) In many areas the direction in which lines may be traversed is limited by the terrain. Under such conditions, the flight should be planned approximately normal to the direction most easily traversed by ground-control parties. Where the area is more suited to the establishment of control by triangulation, the direction of flight has little effect. Consideration should also be given to the use of additional flight lines crossing the main flight lines. Such cross flights may sometimes be used to great advantage to tie in existing control or areas suitable for the rapid establishment of control. Thus they provide additional photogrammetric control for detail plotting.

b. CONSIDERATION OF AREA. The shape of the area to be mapped should also be considered in planning flight direction. In the absence of other requirements, flight direction should cover the area with the fewest possible flight lines, thus using less flying time in turning between flights. The presence of large bodies of water in the area also should be taken into account, and the flight

direction planned either to use the water surface to best advantage or to avoid it. It is not possible to carry photogrammetric control across photographs containing principally water, since no images exist for the necessary measurements. In some cases, the water boundary must be considered as forming an additional limit to the area to be mapped, and control and photography must be planned accordingly. In other cases, flights may be required that will enable the water areas to be bridged over.

c. Cardinal Direction. When none of the above considerations demands that flights be made in a certain direction, it is desirable that they be parallel to the cardinal directions. Such a plan usually aids the work of compiling the map since, almost invariably, the map-sheet boundaries, as finally prepared, follow the cardinal directions. Division of the work for the area into sheets is thus facilitated when flight lines are north and south, or east and west.

22. Products Required

a. General. The products required to be obtained from the air force photographic units vary slightly, depending upon the type of map to be produced, the methods available for the mapping, and the photographic equipment, personnel, and materials available in the engineer organization.

b. Negatives. When the Multiplex equipment is to be used for mapping it is necessary to obtain the negatives. For mapping methods other than the Multiplex, negatives are not necessary if good prints can be obtained.

c. Contact Prints. Since the air force photographic laboratory prepares single-weight prints of all negatives, it is desirable to obtain a complete set. These are sometimes called "quick prints" to indicate they are prepared principally for indexing and preliminary study without much attention to their quality. Such a set of prints is useful to the mapping organization for indexing, general reference purposes, and file purposes. For Multiplex mapping a set of quick prints and the negatives will meet nearly all needs, since such a topographic unit will have contact-printing equipment available. For radial-line, stereocomparagraph, and other methods where precise measurements must be made upon the prints, a set of prints having good photograph quality and good dimensional characteristics is required. When the topographic organization lacks printing facilities, it is advisable to require two sets of such prints in addition to the set of quick prints.

d. Photomaps. (1) For preparing photomaps, two sets of prints suitable for the work are desirable in addition to one set of quick prints. If a mosaic is to be assembled for reproduction as a photomap, the prints must be of a high quality photographically. They should be of medium density, and of as high contrast as is consistent with rendering all detail. The tone of the prints must be uniform throughout the area of each print, and the tone of all prints must be matched. Prints for mosaics are generally prepared on glossy, single-weight paper, without regard for dimensional characteristics.

(2) Organizations which prepare controlled mosaics will require the use of the film negatives for making ratioed prints. It is desirable to furnish film negatives on any mosaicking project where contact printing facilities are available. This enables the organization responsible for the project to do its own tone matching. In cases where the film negatives are furnished, it will generally be necessary to furnish only a set of quick prints.

e. Additional Data. (1) It is also necessary to obtain as much information as possible concerning the manner of photography. It is desirable to know the type of airplane and mounting used for the camera or cameras. These data, together with information supplied by the photographic crew, should indicate what tilts or variations in the tilt may be encountered. Plotting methods may be affected by this information. It is necessary to obtain flight altitude and an estimate from the photographic crew as to its consistency from exposure to exposure. The altitude should have all possible temperature and data corrections applied so as to represent the most accurate determination of the height of the exposures above the ground.

(2) For record purposes, it is desirable to have complete information on the cameras used. For each roll of film the serial numbers of cameras, lenses, and magazines should be obtained. This information is helpful in isolating errors which sometimes arise from faulty camera operations. The focal length of cameras used is also necessary, and should be the actual focal length to the accuracy marked on the lens mounting, and not the nominal focal length.

23. Specifications for Photography

a. DATA SUBMITTED. Specifications for a particular project are probably best worked out in cooperation with the organization which is to do the aerial photography. Complete coordination between photographic and mapping organizations is particularly important in wartime, and requires constant liaison. In requesting aerial photography, the following information should be submitted to the Army Air Forces photographic organization which is to do the work.

(1) An outline of the area on the best available map, in triplicate.

(2) Type of camera to be used.

(3) Photographic scale or altitude.

(4) Forward lap and side lap.

(5) Direction of flight lines.

(6) Number and kind of prints, if desired.

(7) Whether the negative is desired.

(8) Maximum allowable tilt, tip and crab, and tolerance of flight altitude.

(9) Period during which work is to be done.

(10) Any other facts pertinent to the mission.

b. CONFORMANCE. Liaison between the aerial photographic and mapping activities is best maintained if an engineer officer from the topographic unit closely follows the progress of the aerial photography. This liaison can be carried directly to the photographic crews, if the commanding officer of the Army Air Forces photographic organization permits the engineer officer to aid in briefing the crews. The crews will thus have first-hand information of what is desired by the engineer organization. After the photographs are taken, the engineer liaison officer should inspect the quick prints to check coverage and general conformance to the specifications, and designate where reflights are necessary. He should also obtain the information required in paragraph 22*e* as to the manner of performance of the photography.

24. Indexing

a. PURPOSE. Proper indexing of aerial photographs is extremely important. Many photographs are handled during the mapping operations. If they are not properly indexed and filed, much confusion will result. The index facilitates all subsequent operations, including the location, identification, and indexing of existing ground control, planning additional required control, and planning and organization of the compilation, drafting, and reproduction operations.

b. PRELIMINARY. The data noted by the cameraman and kept with each roll of film comprise essential information for indexing purposes. After negatives have been processed this information is inked upon the film at each end of the roll, or at the two ends of each continuous strip, as a permanent record by the Army Air Forces photographic laboratory. These data consist of: organization taking the photograph, mission number, roll number and camera position, negative number, date and time, focal length of camera, altitude, type of photo, and approximate latitude and longitude. Each negative is serially numbered. Details of titles are prescribed in FM 21–25 and Army Air Forces regulations.

c. METHOD. Upon receipt of quick prints by the engineer topographic unit an index of photography is prepared. The object of the index is to have, in a size convenient for handling and study, a sheet showing the relative placement of each exposure with reference to others and with reference to prominent terrain features. With vertical photographs, the index is best prepared by assembling into rough mosaic form a set of prints, trimmed to image edge, by shingling consecutive prints of each strip, and each strip upon the adjacent strip. Large, easily read numbers are placed on each print, and the appropriate title information is placed adjacent to the assembly. The entire assembly is then copied photographically, and reduced in size. Prints made from the negative then will serve for practically all purposes. Such an index is shown in figure 5. Another indexing system sometimes used is to plot the location of each exposure on an existing map, with the necessary title material added. The former method is more easily prepared and more satisfactory, as existing maps are usually too poor for the purpose.

d. OBLIQUE PHOTOGRAPHY. Oblique or combined vertical and oblique photography does not lend itself readily to indexing by preparation of a rough mosaic. This photography must usually be indexed on existing maps by plotting the area each photograph covers.

25. Military Operations

Maps in wartime are often required for areas not immediately involved in operations and not defended or molested by enemy airpower. For such areas, mapping photography can and should be performed according to peacetime requirements. However, enemy opposition, together with the

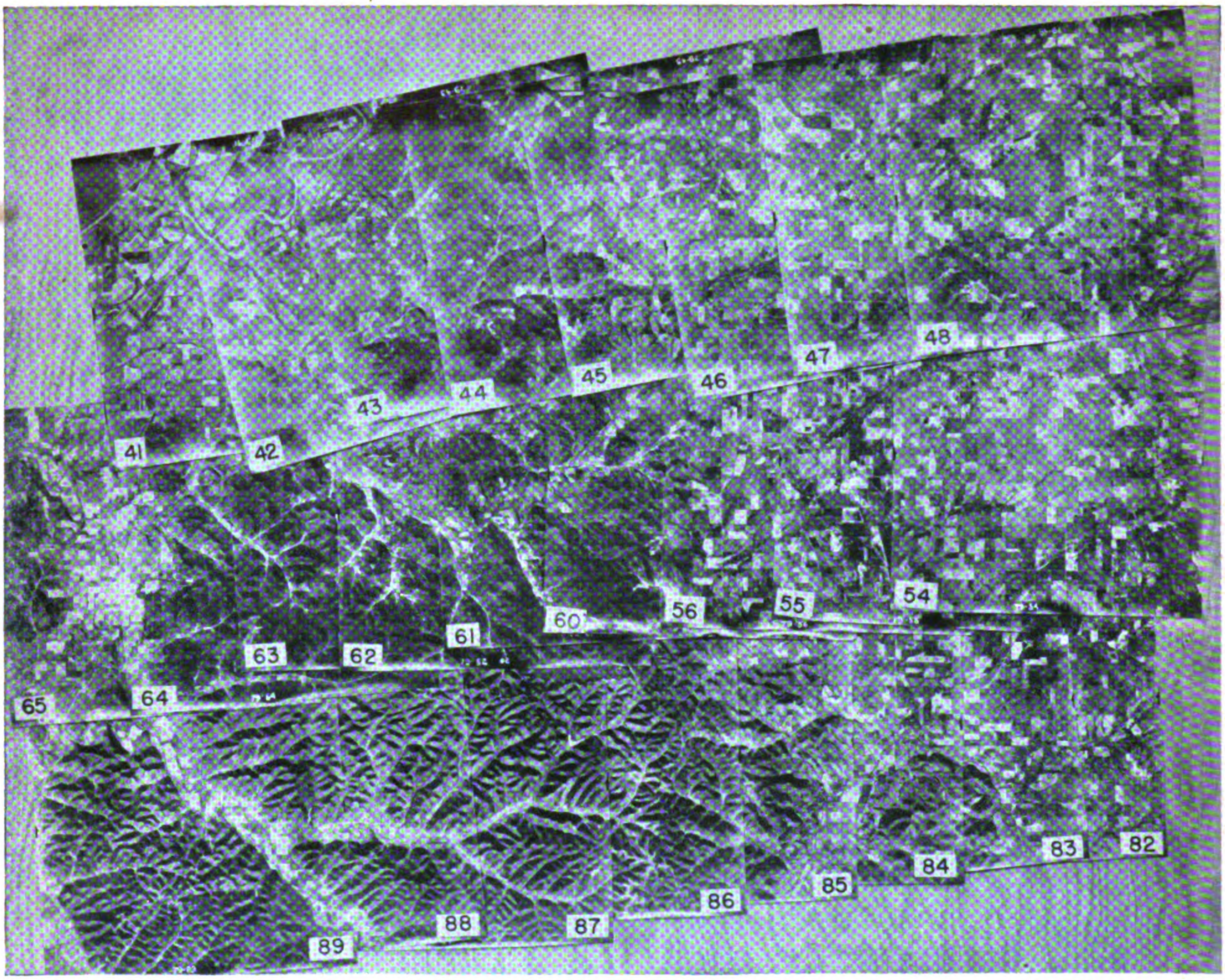


Figure 5. Photographic index.

many dislocations to orderly planning caused by war, necessitates using photography that may not be of the desired quality for mapping. For example, headquarters may be required to change plans upon relatively short notice, and to direct that maps of an area be prepared at once. Sometimes photography must proceed under adverse weather conditions. Enemy opposition may require photographic airplanes to fly at heights too great for the accuracy required in the map. But the map must be made within the time set, and these sacrifices to accuracy and over-all, long-range efficiency must be made. Even in the face of enemy opposition, however, many tactical and technical methods may be employed to obtain photography that will meet most mapping requirements.

SECTION III

GROUND CONTROL

26. General

a. IMPORTANCE. No accurate method of mapping has been devised that does not require some degree of ground-established control. This includes control for both horizontal position and elevation. When great accuracy is not required in a map, certain approximations may result in a satisfactory map without the use of control. These approximations involve the use of flight altitude and estimates of relative elevations of ground features. Even with such approximations, the map can show no absolute position or direction, but its relative values may be satisfactory. For most mapping purposes, however, some ground control is required to establish not only absolute position and direction but also the scale and vertical datum for the map.

b. CONTROL DENSITY. The density to which ground control must be established or available varies with mapping method used, scale of map required, type of aerial photography, and accuracy required. Various mapping methods using aerial photographs make it possible to control successive photographs from preceding photographs and so to bridge between the ground controls. By the same methods it is possible to extend some distance beyond the limits of established control. The best situation is one in which the control appears at small enough intervals to give the resulting map the accuracy required. This usually requires a greater density of vertical or elevation control than of horizontal control, since vertical accuracy is more difficult to obtain by photogrammetric processes than is horizontal accuracy. The control density required for various methods of mapping is discussed for each method in the corresponding chapter.

c. WARTIME OPERATION. In war it is not possible to establish control in territory controlled by the enemy, since most control methods available require that ground be occupied. Aerial photographs are used to extend control into inaccessible territory, and an effort must be made to collect information concerning existing control in that area.

27. Survey Methods

Some of the methods of survey that may be used to obtain the necessary ground control are—

a. HORIZONTAL CONTROL. For the most accurate mapping covering large areas, a network of horizontal control must be established by precise survey methods. By less precise triangulation or traverse work, this network is broken down to the density and accuracy required. The final mapping control which is identified on the photographs is normally located by transit and tape traverse, allowing maximum errors of 1 in 5,000, or even by short stadia traverse. The traverses are located along the most easily traveled routes at the proper spacing throughout the area. In rugged country, it may sometimes be easier and more economical to locate all the horizontal control by triangulation. Such a method requires some easily erected and easily removed signal for the control point intersected. A balloon or searchlight beam has been successfully used for this purpose. As the accuracy required in mapping becomes less, variations of these survey methods are used. For reconnaissance-type mapping and for aeronautical charting, these methods may be abandoned altogether and the quicker and less precise astronomical observation methods may be used.

b. VERTICAL CONTROL. For vertical control, as for horizontal control, a network of points located by precise methods is first set up. This network is then broken down by less precise methods until it is possible to tie in the actual vertical control points on the photographs. The length of stadia level line permissible must be determined from the accuracy requirement for the vertical control points. For less accurate maps, and for reconnaissance mapping, it may be most economical to establish vertical control through use of aneroid barometer elevations. With the best type of barometer, properly used within its limits, it is even possible to establish vertical control for maps of higher accuracy.

c. PERFORMANCE. It is essential that the meth-

ods used in survey work for establishing control points afford complete checks on elevations and positions determined for the control points. Control points should be incorporated as occupied stations in the traverse or level lines, and the lines should be closed upon themselves for more precise work. Where it is desirable to locate a control point not easily occupied, survey methods should be such as to eliminate all possibilities of accidental errors that would not be detected as errors of closure.

28. Control Points

a. Basic Requirement. The basic requirement for the type of control point needed is that the location of the point be positively identifiable on photographs. For horizontal control points horizontal position should be identifiable, and for the vertical control points, vertical position. Points meeting these requirements exist in the necessary density in practically any area to be mapped without requiring special markings on the ground prior to photography. When the area is so wild and undeveloped that identifiable points are few, the scale and accuracy of the map required are usually such that fewer points are sufficient.

b. Type for Horizontal Control Point. Listed below are examples of points suitable for horizontal control.

(1) Right-angle or approximate right-angle intersections of roads, railroads, trails, and canals.

(2) Approximate right-angle intersections of roads and trails with fence, hedge, or field lines.

(3) Approximate right-angle intersections of fence, hedge, or field lines.

(4) Approximate right-angle intersections of ditch lines with any of the above or with other ditch lines.

(5) Corners of wooded areas which have a clear and distinct border with respect to adjacent cleared areas.

(6) Small, lone trees.

(7) Small, isolated buildings.

(8) Corners of large buildings that appear on the photograph at least 1/10 inch long.

(9) Intersections of well-defined drainage lines.

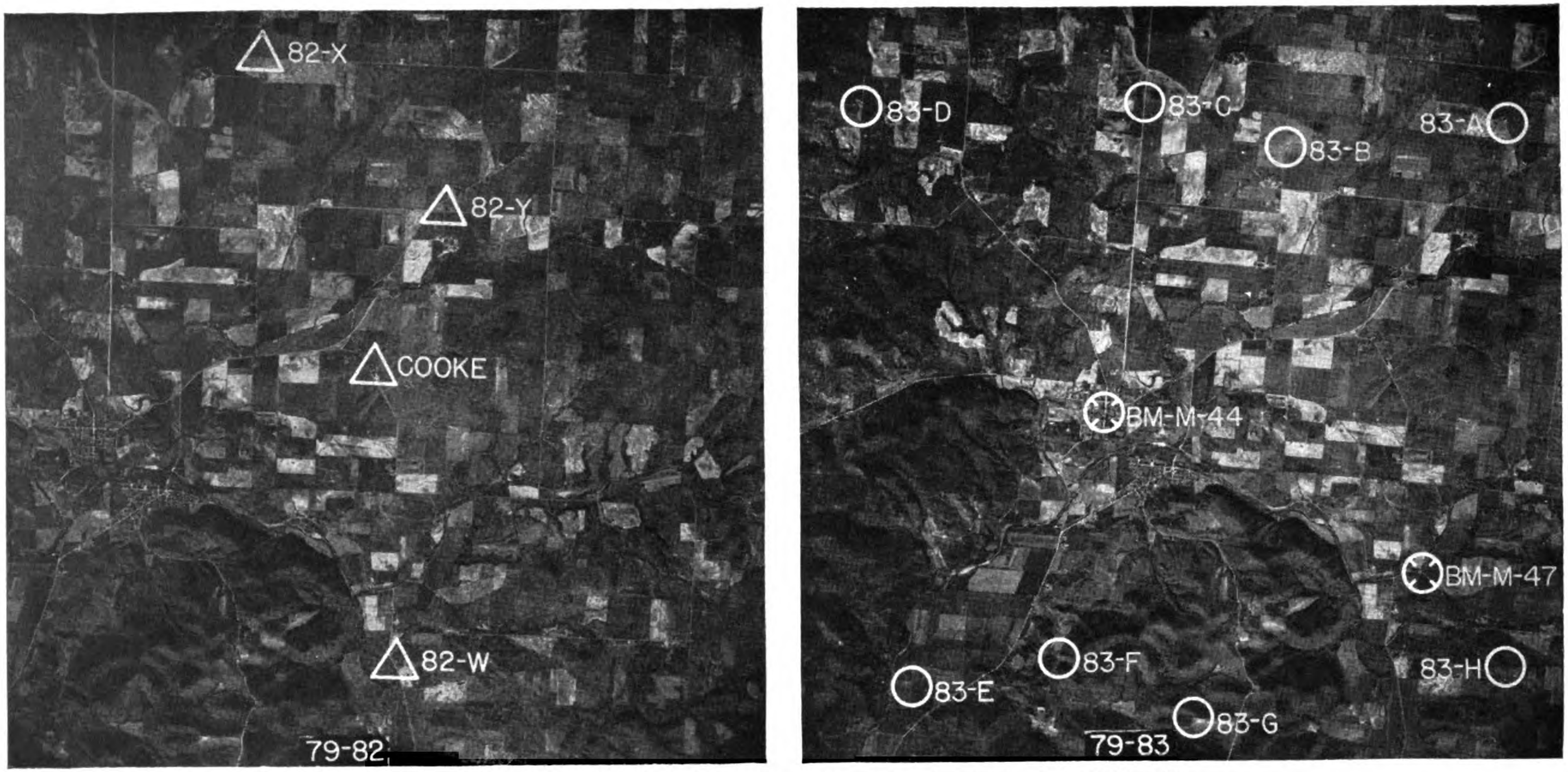
c. Type of Vertical Control Point. While it is not necessary that vertical control points be located on features that fix their horizontal position, they must be located so that their elevations may be determined with necessary accuracy from the stereoscopic model. For stereoscopic measurements, it is also necessary that the vertical control points be located at points recorded on the photograph with definite detail. For example, it is not possible to measure on a sandy stretch that records on the photograph as a uniform white tone, while it is possible to measure at the junction line between the sandy area and an area covered with darker vegetation. Points on a slope may serve for vertical control if they can be definitely identified along that slope.

d. Care in Identification. (1) Too much emphasis cannot be placed upon the care needed in identifying control points on aerial photographs. Many instances have been noted of faulty identification whereby a feature has been identified on the photograph as the control point, when actually the point on the ground was at a different location. Errors, from a few feet to more than a mile, have occurred in this manner. The smaller errors occur more frequently. To avoid them, it is necessary only that sound judgment be exercised.

(2) Consideration must be given to factors which cause the difference in tone on a photograph and to the changes that may occur between the time of photography and the time when personnel actually survey the terrain to establish control. An example of the first is a concrete-surfaced highway having no shoulder on one side, but a wide, graveled strip on the other side. Since the graveled and concrete portions would probably record on the photograph as an unbroken white tone, this must be taken into account when establishing a control point along the road. An example of the second is a field line or boundary line, not marked by a fence between two different types of cultivation. Immediately after the photography, the owner of the area may plow part of the field including the original dividing line, and thus establish a new one. This possibility must be considered by the personnel establishing the control points at some later date.

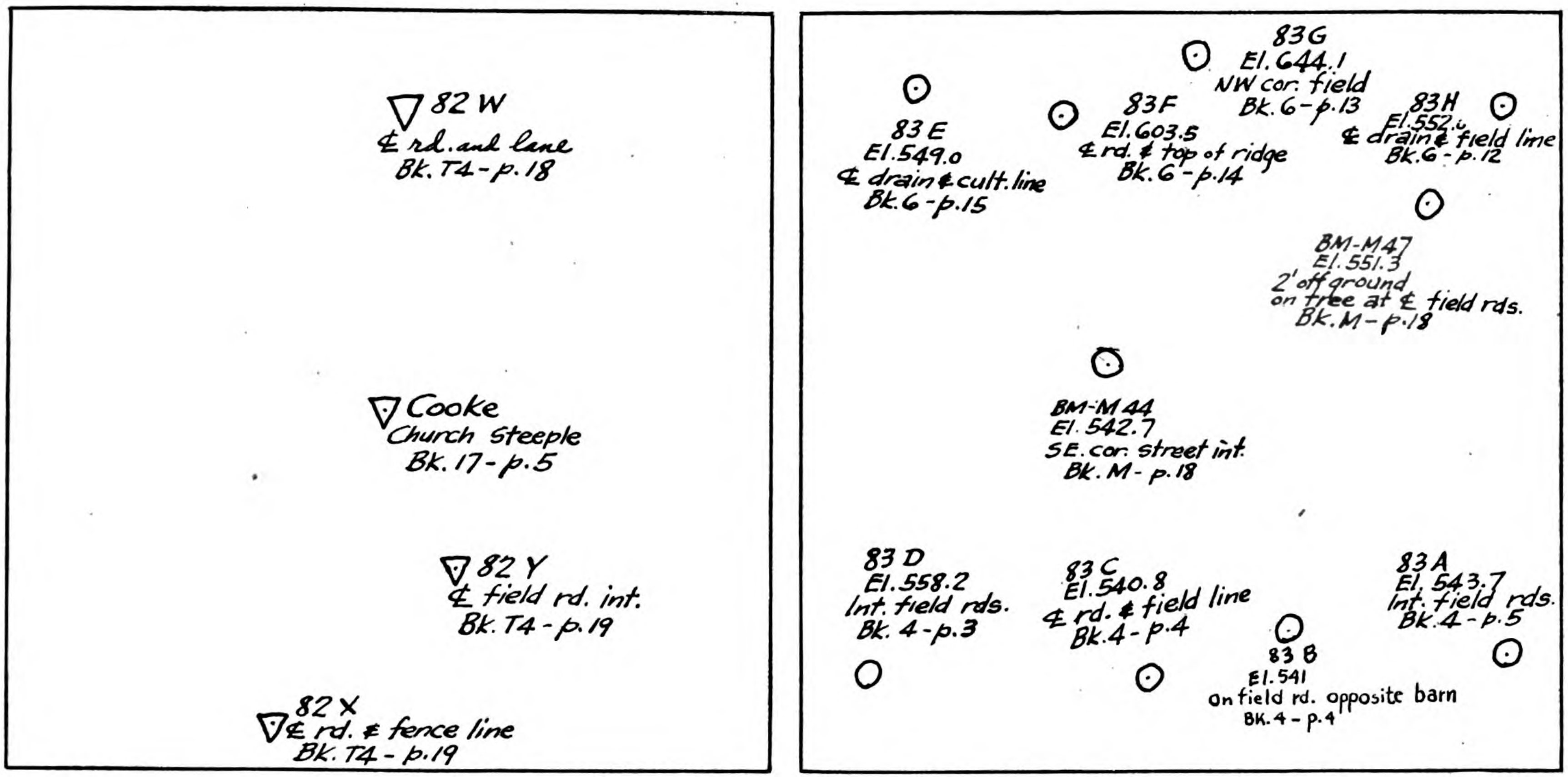
29. Note Keeping

a. There are many suitable methods for recording data collected while establishing ground control. The particular method used is not as important as that some orderly method be established and adhered to. A great quantity of data is collected in the course of a survey, and this data must be kept in a systematic manner in order to be readily available when required. The identifications for the control points are best made



① *Front of photograph. Control points are marked and referenced to field notes.*

Figure 6. One method of indicating control points on photographs.



② *Back of photograph. Data from field notes written directly on back of photograph for ready reference.*

Figure 6. One method of indicating control points on photographs—Continued

at the time the points are established, by pricking a small hole through the photograph at the detail representing the point.

b. On the back of the photograph, an identifying mark may be placed around the hole and the identifying number, letter, or name for the point placed next to it. A description of the point can then be placed beside it, or in the field notebooks. In any event, a reference should be made to the notebook and page where the survey notes for the point are recorded. Likewise, the field notebook should be cross-referenced to the photograph. Figure 6 illustrates one method of indicating control points, where horizontal control points are indicated by triangles on one group of alternate prints, and vertical control points by circles on the other group.

30. Permanent Monuments

a. Since completed maps should show the location of permanent monuments on the ground, data for them must be shown on photographs. Monuments the positions of which have been determined by survey can, of course, be plotted on the map from their coordinates. It is desirable, nevertheless, to have their positions identified on the photographs, since they may serve to strengthen the plotting. Monuments are usually established without consideration for their identification on photographs, and so cannot always be identified positively. However, they should be identified as well as possible. Then, with the description at hand, the mapper can evaluate the reliability of the identification.

b. The position of elevation monuments or bench marks must usually be plotted from photographs. Accordingly, identifications should be made as accurately as possible. Descriptions of monuments are of great aid when they refer positions and elevations to features that show clearly on photographs. For example, the description of a bench mark established on a bridge foundation should include the approximate distance down to the bottom of the stream bed or top of the bank. The description of a monument established for position in the corner of a field near a road intersection should include the distances from the monument to the edges or to the center line of the roads, whichever are more definite on the photograph.

31. Classification Data

a. Personnel engaged in establishing the ground control also collect all information needed to complete the map in all its details and which cannot be determined in the office by interpretation of the photographs. Such information includes data on names of places and features; identification of schools, churches, public buildings, and cemeteries; location and identification on the photographs of political boundaries and land-subdivision lines; location and identification on the photographs of all overhead and underground utilities; and location of any other features to be shown on the final map which can not be identified on the photographs alone.

b. Where any of the above features can be recovered on the ground but cannot be identified on the photographs well enough to be plotted on the map with the desired accuracy, they may be tied in for position by traverse. Data collected for these purposes may be shown by pricking the location on the photographs and by writing names and identification data on the front or back of photographs or photographic indexes. A systematic method must be adopted and adhered to in order to eliminate confusion in the assembly and use of this great amount of data.

32. Control Planning

Control is best established after aerial photography. This arrangement can be planned and is the most economical. Since the requirements for placing control with respect to the areas covered by the photographs are rather rigid, much more control would have to be executed in advance to assure its proper distribution on photographs taken later. Placing control after photography also prevents many errors of identification. Also since the photographs usually provide a much better picture of ground conditions that affect the ease of establishing control, a more economical layout may be planned with less ground reconnaissance. Too much emphasis cannot be placed upon the need for a well-planned control network that will meet map requirements and yet can be established with a minimum of work. The control operation is the most time-consuming part of map preparation, and it should be kept to the minimum consistent with required accuracy.

SECTION IV

MAP PROJECTIONS

33. General

The subject of map projection is complex, and the greater part of the subject is beyond the scope of this manual. The study of map projections usually applies only to the preparation to small scales of maps of large areas. In representing large areas on a plain map sheet, the distortion of shapes, areas, and directions becomes pronounced. Much study goes into the projection upon which maps are based so as to reduce the distortions to a minimum, or to achieve accuracy in representation of some characteristic at the sacrifice of others. But these maps are usually compiled from existing maps, and the map data are rearranged or clarified only for some particular purpose. The same problems are not involved in the projections used for mapping from aerial photographs, since the areas covered on any given project are relatively small and the map scales are relatively large. Comments in this chapter are confined to mapping from aerial photography. For more information concerning map projections refer to appropriate publications listed in appendix II.

34. Projection Systems

a. Most Suitable Type. The type of map projection desired for mapping from aerial photographs is one that most nearly represents an orthographic projection of the area involved, this projection being made upon a plane tangent to the earth's surface at the center of the area to be mapped, or of subdivisions thereof, or upon a secant plane parallel to the tangent plane. An aerial photograph, aside from perspective distortions, may be considered an orthographic projection of the section of the earth which it covers, since the section considered is so small that its datum may be considered a plane. Thus, the scheme adopted for representing the latitude and longitude lines on a sheet of paper, that is, the map projection, must be close to an orthographic projection, or the photographs cannot be made to fit.

b. Polyconic Projection. (1) The map projection most widely used in the United States, and one well suited for mapping relatively small areas, is the polyconic projection. The greatest advantage of the polyconic projection is that all the data are computed for it and arranged in tabular form directly applicable throughout the world, regardless of latitude or longitude. It is only necessary to apply the mapping scale factor to the tabular values in order to obtain the necessary data for plotting the projection.

(2) The distortion of polyconic projection is negligible for small areas, and that projection results in the desired orthographic representation. Distortion increases as the area covered increases in the longitudinal direction. This distortion results in a larger scale north and south at the edges of the area, while the scale remains true in an east-west direction. For an area covering 3° in longitude (approximately 150 miles at the middle latitudes) the distortion in scale amounts only to 0.02 percent, which is negligible. Even on a map sheet 100 inches long covering the area in the north-south direction at the final scale, the distortion would amount only to 0.02 inch. So large an area seldom needs to be mapped as a single unit. The location of control usually requires the area to be broken into smaller projections for mapping operations.

(3) The polyconic projection is well suited to mapping even larger areas extending principally north and south, or areas extending greater distances east and west when the north-south dimension is small. Not more than about 5° of longitude should be included in any one projection. Details for constructing the polyconic projection are given in TM 5–230 and in Special Publication No. 5, U. S. Coast and Geodetic Survey.

c. Other Projections. Several other types of map projection have been devised which will approximate an orthographic projection when used over small areas. The Mercator projection is suitable for mapping with aerial photographs only areas in the equatorial zones. The transverse Mercator projection is suitable for maps of areas which are elongated in one direction. The Lambert conformal conic projection is suitable for areas extending principally east and west, and when the

standard parallels are not too far apart. Since all these projections must be specially computed for each area to be mapped, the data for their plotting are not readily tabulated for universal coverage. Projections of these types have already been computed and tabulated for all States of the United States for the purpose of standardizing a plane coordinate system. These projections are generally used on foreign maps.

d. Projections for Aeronautical Charts. (1) A special application of map projections is in the preparation of aeronautical charts. With the increase in long-distance flights and the trend toward more extensive use of air travel throughout the world, better aeronautical charts are needed. This preparation will involve original mapping in many parts of the world, as existing map data are too poor to be incorporated into aeronautical charts. One of the prime requirements for aeronautical charts is that true azimuths may be scaled with a minimum of error from the charts covering large areas. Also, distances must be shown to a fair degree of accuracy. The azimuth requirement is the more important.

(2) To meet these requirements, four projections completely covering the earth have been established and computed. They have sufficient overlap so that borders may be crossed with a minimum of difficulty. The projections are all conformal; that is, they show correct shapes, and hence correct azimuths. The equatorial band is covered by a Mercator projection, the middle latitudes are covered in two steps by two Lambert conformal conic projections, while the polar zones are covered by stereographic projections. The actual preparation of an aeronautical chart from aerial photographs may still be done on the polyconic projection, since any area included in any subdivision of the work will be compiled at a larger scale and will be practically an orthographic projection. Such an area can readily be adjusted into the other projections.

e. Plane Coordinate System. Small areas may be mapped satisfactorily on a plane coordinate system in which control surveys are computed as though they were actually executed on a plane instead of on the curved surface of the earth. The resulting map is practically the orthographic projection desired, and can be fitted to any later determination of absolute position without change. Such a system should not extend more than about 30 miles in an east-west direction, however, since beyond that distance the convergence of meridians is significant. The north-south dimension is not critical, and may be as great as desired. Since it is desirable to have all maps based on a common datum referred to the curved surface of the earth, the plane coordinate system is seldom used. Its greatest application is in large-scale mapping of extremely small areas not readily tied into the common datum.

35. Grid Systems

a. Relationship to Projections. Rectangular grid systems which appear on maps, principally military, should not be confused with the plane coordinate system (par. 34*e*). Grid systems are based upon the curved surface of the earth and on some definite scheme for representing that curvature on the plane map sheet, that is a map projection. Actually, the map projection is adopted first for the area involved, so as to represent that area with the minimum of distortion. After the map projection is determined, some point on it is chosen as an origin for a rectangular grid, and some direction is chosen for orienting the grid. The grid is then superimposed upon the map projection and extended throughout the entire area which the projection was designed to cover. A definite relationship then exists between any grid intersection and any adjacent intersection of latitude and longitude lines on the map projection. Data for determining this relationship may be precomputed and made available in tabular form, or may be given by the necessary formulas for their computation. The former method has been used in the United States in preparing the data for State plane coordinate systems and for the military grid system, while the latter method is used principally by foreign countries.

b. Military Grid. The military grid system, described in Special Publication No. 59, U. S. Coast and Geodetic Survey, has been prescribed for all military maps in this country and certain other areas of the world where military operations may be carried on. The tables in Special Publication No. 59 have been extended by the War Department to include all areas from 72° south latitude to 72° north latitude. The necessary tables, in addition to those contained in Special Publication No. 59, are available to authorized agencies upon request to the Chief of Engineers.

c. Description. The United States military grid system is based upon a polyconic map projection

constructed so as to cover 9° of longitude and an unlimited extent in latitude. The earth's surface is divided into zones for applying the projection, the center of each zone being 8° of longitude from the center of adjacent zones. Thus, there is an overlap of 1° of longitude between zones. At the middle of this overlap, or at 4° from the central meridian of the projection, the projection has a distortion of about 0.14 percent in the north-south direction. This distortion is of little significance on final maps, but may be noticeable in the process of compiling a map on this projection.

d. Use. A map in process of compilation, on a grid system, is actually being compiled upon the map projection on which that grid system is based. The grid coordinates of any point refer its position directly to its latitude and longitude through the relationship existing between grid and projection. Both grid lines and latitude and longitude lines must usually be shown on the map, and the azimuthal relationship between them must also be shown. To the organization compiling a map, the advantage of using the grid is that after a standard base sheet or template is once laid out at the plotting scale, the template can be reused as the projection for any areas where mapping is required at that plotting scale. When the polyconic projection is used, the projection must be plotted for each area in which a different latitude is used. The grid is also of particular interest to using agencies. It provides a convenient means of designating points or areas on the map by referring them to grid coordinates, and it provides a base for local surveys so that they may be conducted as though on a plane and yet be coordinated with the map projection with a minimum amount of computation. The latter is of particular importance to the artillery.

e. Grid Applied to Other Projections. (1) A grid system for a given area may be placed upon a map of the area which was not based upon the same projection as the grid, by obtaining the grid coordinates for the intersections of the latitude and longitude lines on the map and then, working backwards, plotting the grid lines from the parallels and meridians. Data for performing this operation with the United States military grid are given in Special Publication No. 59, U. S. Coast and Geodetic Survey. The methods are directly applicable to other grid systems. However, when this procedure is used the resulting grid on the map may not be rectangular or of equal spacing in both directions, since two different map projections having different distortion characteristics are involved. In some cases, departure from a rectangular system may be quite pronounced.

(2) The method of placing the grid, as described in Special Publication No. 59, may even have to be elaborated upon when the difference in projections is great, so more grid intersections are plotted directly from the parallels and meridians. The object is to be able to scale the proper grid coordinates for all geographic positions on the map. When this condition is achieved, the maps may be used and the grid coordinates scaled from them in the same manner as though the map were based upon the proper projection for the grid system.

f. British Grid Systems. All of Europe, Africa, and Australia, and a large part of Asia, have been covered by British grid systems. These continents have been divided into small areas, and a different grid system having its independent origin of coordinates has been applied to each. These grid systems are based on the transverse Mercator, the Lambert conical orthomorphic, or the Cassini-Soldner projection. When mapping these areas, the British grid system applicable to the area is normally used. Data for the projection and grid system used in each area are available to authorized agencies upon request to the Chief of Engineers.

36. Application

a. Control Base. In the actual plotting of a map, the map projection serves as the means for plotting horizontal control points in their correct relative positions, so that they may be used to establish the correct scale for mapping. This scale, in turn, provides a base upon which all features plotted will be shown in their correct horizontal positions with respect to the control datum. Where other means exist to establish the scale of the plotting, and where absolute position and direction are not necessary—which seldom occurs—no projection is required.

b. Scale of Projection. The projection selected for use in mapping an area is plotted at the scale at which the plotting is to be done. For radial-line mapping methods this scale is usually the average scale of the photographs, or an even scale nearest to this average. For the Multiplex method of mapping, the plotting scale is determined by the ratio of the most favorable projection distance to the flight altitude above the average ground elevation. When mapping from

oblique photography, or from combined vertical and oblique photography, the plotting scale is usually somewhat less than the scale of the vertical photograph or equivalent vertical photograph.

c. Size of Projection. The area included in the projection varies from project to project. It may be desirable to include in a single projection the entire area to be mapped, but this may not always be possible in excessively large areas, in which case the project is divided into sections for the layout of the projection. Such sections may be joined as necessary to bridge between the controls lying in the separate parts.

d. Projection Templates. Templates may be used to advantage in laying out projections where many of a similar nature are required. They are of particular value if a grid system is used as the basis of control plotting, since the spacing of the grid net is the same, no matter what the latitude and longitude. Templates may be prepared on any material of suitable size and having favorable dimensional stability. Plywood panels painted to reduce moisture absorption, or masonite panels may be satisfactory. A satisfactory surface may be obtained by painting, or by cementing drawing paper to the base. The basic grid or projection dimensions may be laid out on such a base and used to construct the projections on many other sheets by tracing the lines on a transparent material or by connecting the proper lines appearing at the edges of opaque material. It is preferable to have each projection to be used constructed on plywood or masonite.

SECTION V

CHARACTERISTICS OF AERIAL PHOTOGRAPHS

37. General

a. The characteristics of aerial photographs must be understood if they are to be used intelligently in compiling maps. The fundamental point is that the aerial photograph is not a map. The basic reasons for this are: the photograph is a perspective projection of three-dimensional terrain on a two-dimensional plane; it is almost impossible to expose the negative so that it is absolutely parallel to the corresponding ground plane; and the camera lens is not entirely free from distortion.

b. The first two of these reasons may be stated in photogrammetric terms as follows: image distortion exists in photographs due to ground relief and tilt. However, for practical purposes a photograph may be considered a map if the terrain included in the entire area of the photograph is flat, if the photograph is not tilted, and if the camera lens is precise. Since these conditions rarely exist together, it is necessary to convert to the true the distorted relationships between ground features.

38. Distortion Due to Ground Relief

a. Basic Principles. (1) In considering relief distortion, let us assume the photograph to be a truly vertical photograph. Figure 7 shows a typical section of terrain photographed by L, the camera lens. Points D, P, and C are points on the ground. Since point P is the intersection with the ground of the plumb line from the camera lens, it is called the plumb point. The line LP is the camera axis as well as the plumb line. The extension of the line LP to the plane of the photograph, cd', intersects this plane in point p, which is the principal point since it is the position at which the foot of the perpendicular from the lens strikes the plane of the photograph. Point p also is the image of the plumb point on the photograph. Since true horizontal distances are required in map making, the ground distance DP must be plotted on the map as $D'P'$, and the distance PC as $P'C'$. But the recorded images of points D and C on the photograph, d and c, are such that these points correspond to points D'' and C'' on the datum plane. An error of $D'D''$ and $C'C''$ would therefore exist in the map, caused by the relief of the terrain.

(2) The corresponding errors at the scale of the photograph, dd' and cc', are image distortions caused by ground relief. It is seen that d is displaced inwardly from its true position d', and c is displaced outwardly from its true position c'. Since d is the image of a low point of the terrain, and c of a high point, it is evident that, in relief distortion, points lower than the datum plane are displaced toward the center of the photograph and high points are displaced away from the center. In mapping, displacement inward rarely occurs, since sea level is ordinarily used as the datum plane and ground positions are generally higher than sea level. It is also seen that the displacement of images occurs along the line connecting the image with point p. It will be shown later in this section that this displacement is radial from the plumb point of the photograph. It will also be apparent from a study of figure 7 that an object appearing at the plumb point will not be displaced on the photograph, regardless of the relief of the ground or the datum plane which is used.

b. Appearance of Regular-Shaped Image Due to Relief. Figure 8 shows a horizontal plane containing four objects, A, B, C, and D, the elevations of which vary as do all points in rugged terrain. Point D lies in the datum plane. The map positions for all these points must lie in the datum plane, with the result that true distances between them are measured by the distances DA', $A'B'$, $B'C'$, and $C'D$, which form a square. Upon this horizontal plane is superimposed a truly vertical photograph having the same scale as the square. If all objects forming this square were of the same elevation, the points would also form a square on the photograph. But distortion resulting from the variation in elevation of the four objects causes them to appear at A'', B'', C'', and D on the photograph. The square formed by the objects on the horizontal plane (ground) is thus distorted into the figure $A''\ B''\ C''\ D$ on the photograph. Fig-

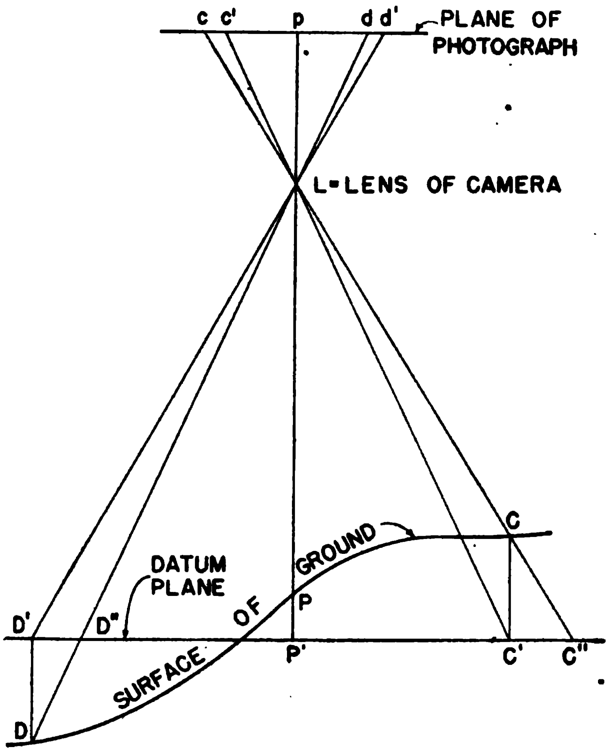


Figure 7. Displacement of images caused by relief.

ure 8 also illustrates the fact that the displacement due to relief occurs along the line connecting the image with the plumb point.

39. Distortion Due to Tilt

a. In distortion due to tilt, the problem deals with the perspective projection of features from a horizontal to an inclined plane. Figure 9 introduces the relationship between these two planes. *A*, *B*, *C*, *D* can be considered the image of a square object which is recorded on a truly vertical photograph. Now, if the camera were tilted as shown in the section, the resulting tilted plane of the photograph would intersect the plane of the vertical photograph at I, which is known as the isocenter of the tilted photograph. By geometry, *I* lies on the bisector of the tilt angle *t*, *P* is the principal point, and *N′* is the plumb point of the tilted photograph. The corners of the square would be recorded in the tilted plane as indicated by *A′* and *B′* in the section.

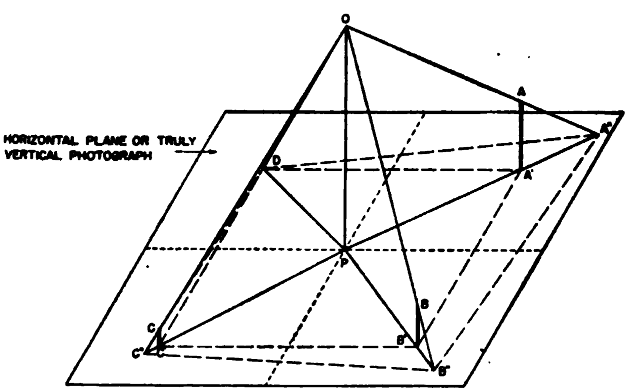


Figure 8. Diagram showing distortion of images in a vertical photograph caused by relief.

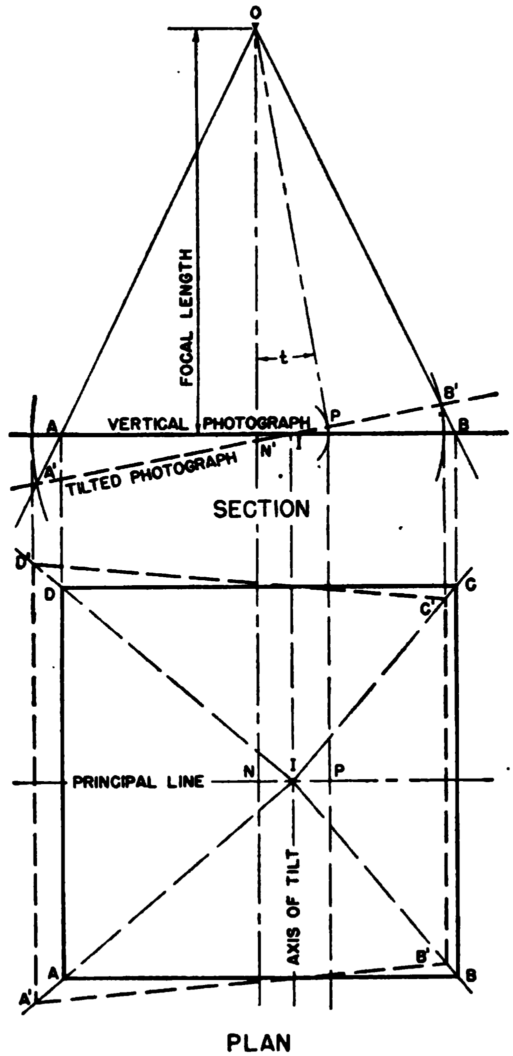


Figure 9. Effect of tilt on image of a square object.

b. By pivoting the tilted plane on the axis of tilt until it lies in the horizontal plane, the shape of the square takes the trapezoidal form *A′ B′ C′ D′*, as shown in the plan. The distance between the parallel sides of this trapezoid is determined readily from the section. The distance *B′ C′* is determined from the proportion $\frac{OB'}{OB}=\frac{B'C'}{BC}$, while *A′ D′* is determined from $\frac{OA'}{OA}=\frac{A'D'}{AD}$. Of significance in this plan view is the fact

that the lines connecting the isocenter I with the corners of the trapezoid also intersect with the corners of the square. This is indicative of the characteristic of the isocenter of any tilted photograph—that angles measured from this point are true. This and other characteristics of the tilted photograph can be seen from the geometry of perspective projections.

40. Geometry of Perspective Projections

a. GENERAL. (1) Figure 10 shows a bundle of rays cut by two planes, I and II, which intersect along a line QR at an angle t. Plane I may be considered as the plane of the oblique photograph, and plane II as the object plane, or plane of the ground photographed. Point S, which is the perspective center, is analogous to the lens of the aerial camera. The foot of the perpendicular from S to plane I falls at the point p, which is the principal point of the photograph. The foot of the perpendicular from S to plane II falls at point N, the plumb point of the exposure station. The lengths of the two perpendiculars are f and H, the focal length of the camera and the flight height, respectively.

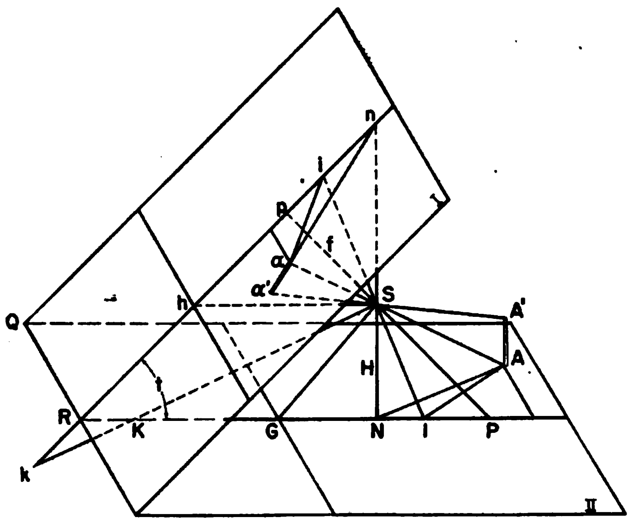


Figure 10. Intersection of perspective bundle of rays by two planes.

(2) The principal plane of the system is the plane perpendicular to the planes I and II and containing the perspective center S. This plane, SNR, is also perpendicular to the line QR, the intersection of the planes I and II. The lines through either h or G parallel to QR contain all the infinitely distant points of the other plane; hence, the line through h is the true horizon on plane I, and contains the images of all infinitely distant points on plane II. Also, all parallel lines in plane II will converge to the same point on the true horizon. The bisector of the interior angle, NSP or nSp, between the perpendiculars to the planes I and II, intersects the planes at points i and I, respectively. The bisector of the exterior angle, NSp or PSn, between these perpendiculars, intersects the planes I and II at k and K respectively. These four points i, I, k and K, are known as the isocenters. In the plane of the photograph, then, there are two isocenters, but usually only one will appear within the area of the photograph. Any point such as A in plane II has a corresponding projected position a in plane I. Such pairs of points as A and a are called homologous points, and their positions in their respective planes have corresponding geometrical relationships to all other points in the same planes.

b. DIRECTIONS FROM ISOCENTER. Proof that angles measured from the isocenter are true is in figure 10. The angle measured at the isocenter i on plane I (aip) must be proved equal to that measured from isocenter I (AIP) on plane II. The proof lies in the angular relationship existing between the line bisecting angles NSP, or nSp, and the two planes. Since line Ii is the bisector of angle NSP, and angles ipS and SNI are right angles, angles NSI and pSi are equal, and triangle NSI is similar to triangle pSi. By similar triangles, angles Sip and SIN are equal, and the line iSI intersects the two planes at the same angle. Angles aip and AIP are equal, due to the symmetry about the line iSI. This angle-true position, however, is valid only when the ground point to which direction is to be measured is in the datum plane, such as A in plane II. If this point lies in a different plane such as A', this angle-true relationship no longer holds. Therefore, in a tilted photograph of terrain with relief, there is no point having angle-true properties. This fact can be best exemplified after a discussion of the plumb point.

c. DIRECTIONS FROM PLUMB POINT. In figure 10 point A' is located vertically above point A in plane II, and its image falls at a' in plane I, which is on the line radial from the plumb point n through a. That this is true is obvious, as the plane containing the line Nn and the point A will be vertical, and will also contain the point A'. The intersection of this vertical plane with plane I is in the line na; therefore, the image of A' must likewise

fall on this line of intersection, or at a'. Thus, straight lines on the ground, radial from the plumb point, will photograph as straight lines radial from the plumb point on the photograph. Or, a straight line on the photograph, radial from the photo plumb point, contains all details existing on a straight line on the ground which is radial from the plumb point, regardless of relief. But, the angle between radial lines on the photograph at the plumb point is not the same as though measured on the ground, since the symmetrical relationship existing between the points I and i in the two planes does not exist between points N and n. It is possible, however, to determine the angle at the ground plumb point N from the angle measured at point n on the photograph, if the distance f and the angle t are known. The determination will be shown in section VII.

d. **Effect of Relief and Tilt on Angle-true Position.** By further reference to figure 10 it can be assumed that point A' is any point on the ground higher than the datum plane. Its image is recorded at a' on the tilted plane and the image of the orthographic projection of A' on the datum plane would be recorded at a. However, in a tilted photograph of undetermined tilt, the position of the plumb point and the elevation of any point above or below the datum is unknown, and therefore only the image of that point is in evidence. In figure 10 that image is a'. If, then, a ray is drawn from i to a', the resulting angle between the line ia' and ip would obviously not be equal to the corresponding angle measured at points I on the ground. This angle is measured from a line drawn to a. The diagram in figure 11 is a plan view of this condition. When supposedly vertical photographs are tilted, though not obviously, they must be used as though they were truly vertical, in which case angles would be measured from the principal point, as angle 1 in figure 11. Now, theoretically, angle 3 is the correct one, but practically, since there is no evidence of position other than that of a' on the photograph, there is no point

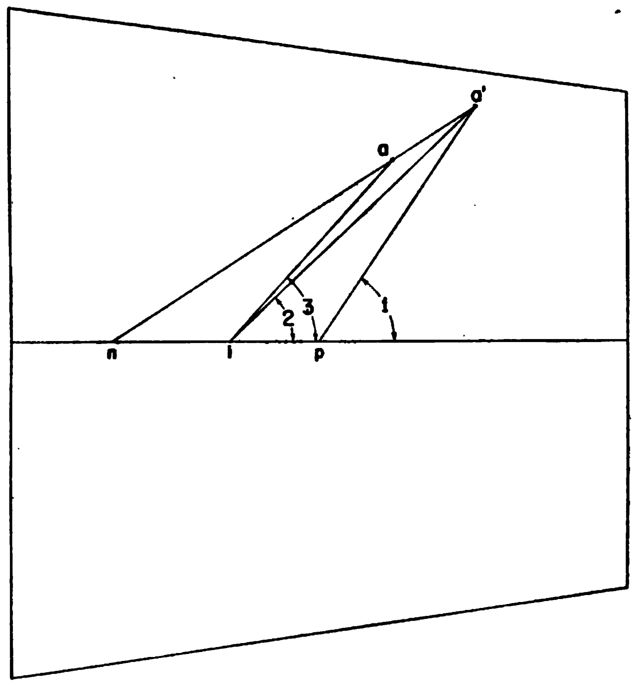


Figure 11. Angular relationship caused by tilt and relief.

on the photograph from which angular measurement is true when relief and tilt are combined. However, it can be seen that when the tilt is small, points n, i, and p are more nearly coincident, and the angle obtained by the use of point p therefore would be close to the true angle.

SECTION VI

RADIAL-LINE MAPPING

41. General

a. Graphical Method. There are two general methods of compiling maps from aerial photographs—the graphical method and the stereoscopic method. The radial-line system is the basic graphical method for compiling maps from vertical, or near vertical, aerial photographs. Graphical methods in use for mapping from oblique photographs, or from a combination of vertical and oblique photographs, are ramifications of the radial-line method and will be discussed in section VII. The radial-line method is really a system of graphical triangulation for establishing intermediate control points to supplement ground control points. While this system is not new, many different methods facilitating its use have been devised. Mechanical methods of accomplishing the graphical intersections of the radial-line system have been developed; and in the last decade, while stereoscopic methods have rapidly become practical, the radial-line system remains a practical method for many mapping projects.

b. Use. The primary use of the radial-line system is in planimetric mapping at a scale equal to or smaller than the scale of the photograph. Since by the radial-line method a planimetric map can be produced in a comparatively short time, it is used in compiling of reconnaissance-type maps of areas of which terrain intelligence is desired immediately and of which existing maps are poor or nonexistent. Radial-line triangulation is also used as the base for laying controlled and semicontrolled mosaics.

c. Contouring. It is possible, but impractical, by mathematical calculations to determine elevations from photographs in conjunction with radial-line triangulation. Where the radial-line system is used and contours are desired, they are added by use of the stereocomparagraph, as described in section IX, or by the use of the plane table in the field. In the latter method, contours may either be plotted on the photograph in correct relation to the planimetry, so that they may be transferred to the radial plot simultaneously with it, or they may be plotted on the planimetric maps after their completion. When contours are required on the map, the Multiplex method is normally employed. However, when Multiplex equipment is not available in the organization, or is being employed on more important work, other methods of contouring the planimetric map compiled by the radial-line method must be used.

42. Purpose

The purpose of radial triangulation is to establish the true positions of the photograph centers and other image points on the photographs in order to create a density of control points which will insure the position accuracy of the planimetric features traced within them. A system of control points established by the radial-line system is pictured in figure 12.

43. Principles of Radial-line Mapping

a. Vertical Photographs. (1) Radial lines are lines drawn radially through image points on the photograph from its center. Use is made of the characteristics of the photographs whereby relief distortions are radial from the plumb point and tilt distortions are radial from the isocenter. In vertical photographs the plumb point, isocenter, and principal point coincide, and since there is no tilt all significant distortion is due to relief alone. The principal point, in this case, is the true radial center, and therefore all lines drawn through images from this point contain the true positions of the images. Therefore, if two overlapping photographs are oriented so that the lines on each photograph joining the principal point images coincide, the intersections of radial lines through any images common to the photographs will establish the relative positions of those images with respect to the principal points. This is shown in figure 13. Thus, by orientation of the first pair of overlapping photographs to a desired scale, the relative positions of image points appearing on them can be established for the purpose of establishing relative positions of image points on suc-

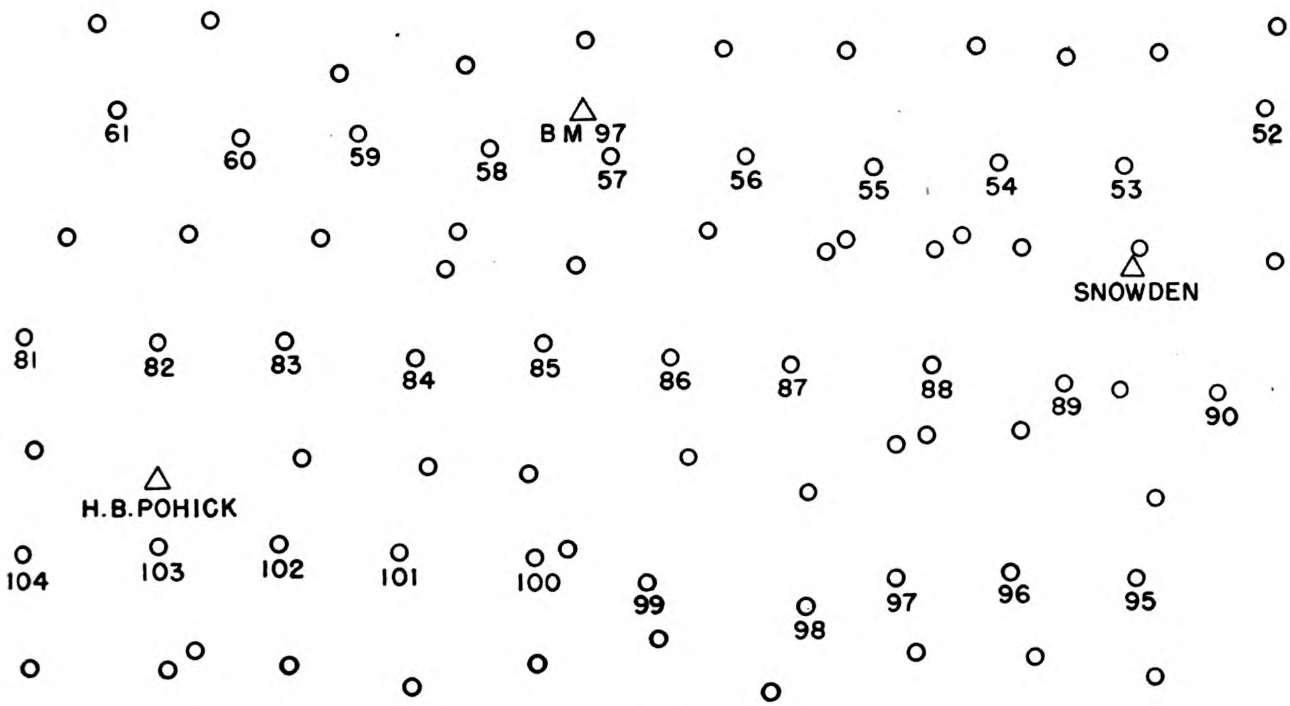


Figure 12. System of control points.

ceeding photographs. In figure 13 the intersections of C_1 and C_2, and D_1 and D_2, locate the positions of C and D, the newly established control points. Points C and D are used in the orientation of the third photograph, whereby the radials through these points on that photograph are oriented on the two line intersections, while the azimuth lines remain coinciding. Then points E and F are established, and are used in the same manner to continue the orientation of subsequent photographs until additional ground control is reached. These newly created control points must appear in the overlapping areas of three successive photographs. The rectification of relief distortion by radial line is exemplified by a comparison between figure 13 and figure 7. Points D and C correspond in both figures. This process of control extension is known as radial triangulation.

(2) The principle of radial triangulation may be likened to the three-point problem in surveying, in which the position of any point can be determined from the established positions of three other points merely by measuring the two angles from the fourth point between the three established ones. In the radial-line process, the same principle is applied when the position of the center of each succeeding photograph is determined graphically by resection of rays passing through the preceding side-control points and the preceding photograph center.

b. Tilted Photographs. The radial-line system is feasible in truly vertical photographs regardless of the amount of relief. However, in titled photographs, lines drawn through image points contain their true positions only when drawn radially from the isocenter and when there is no ground relief. If the tilt is under 3°, and the ground relief does not exceed 10 percent of the flight altitude, the principal point may be used as the radial center and the radial-line system can be used without difficulty. If the tilt exceeds 3°, the system remains feasible if the tilt is known and the isocenter can be located for use as the radial center, providing the amount of relief is small. This is shown in figure 14. However, such a system is impractical. In greatly tilted photographs having marked ground relief, the normal radial-line system is not feasible for reasons explained in section V.

c. Triangles of Error. (1) *Effect of tilt.* When nearly vertical photographs are used in mapping by radial-line triangulation it is assumed that tilt is negligible, and the principal points are used as radial centers. Now, if the drafting and extension are done carefully and the assumption that tilt is negligible is correct, the triple intersections of lines through common image points will be ideal, as

shown in figure 13. However, if there are significant tilts, triple intersections of rays through common image points will not occur and triangles of error will appear, as shown in figure 15. Excessive tilt causes large triangles, and the system becomes unreliable. Small triangles of error are balanced out, an average position is selected as shown in the figure, and the extension is continued in the usual manner.

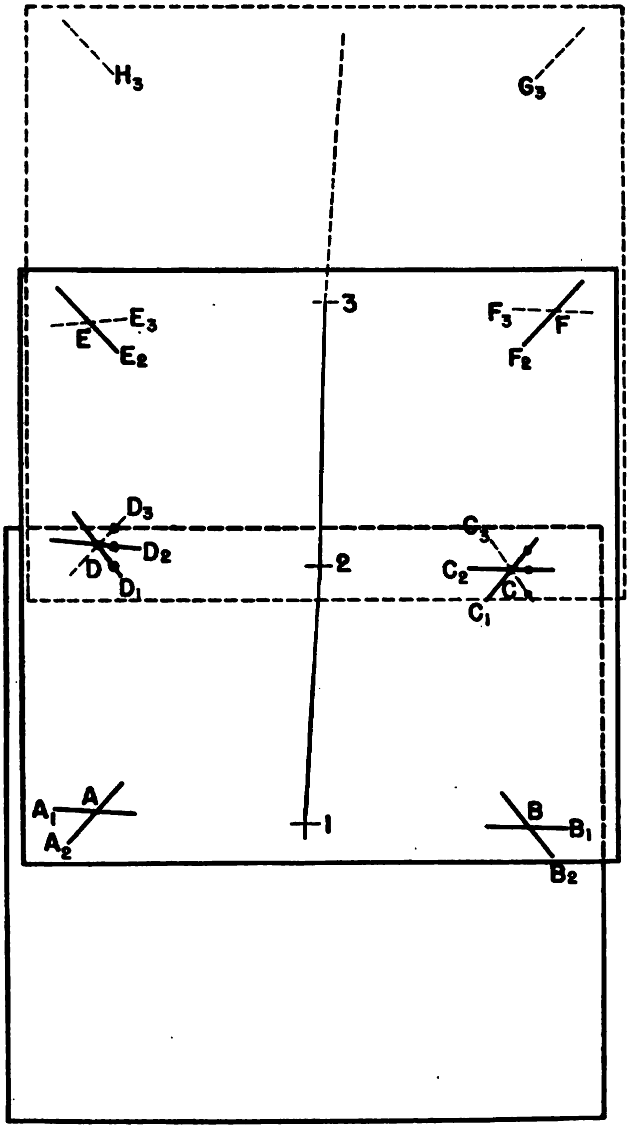


Figure 13. Establishment of positions by radial-line triangulation.

(2) *Effect of inaccurate drafting.* Triangles of error will also occur in the absence of tilt when the selection of points and the drafting operation in the radial extension are not done carefully. The radial extension is such that an erroneous start will cause accumulation of errors which become significant by the time further control is reached. While errors due to poor drafting may not appear significant in local areas, great difficulties are encountered as the extension progresses. Triangles of error may appear without local evidence of faulty drafting, but may be traced to faulty drafting in some previous photograph or template. The importance of precise point identification and template preparation cannot be overemphasized.

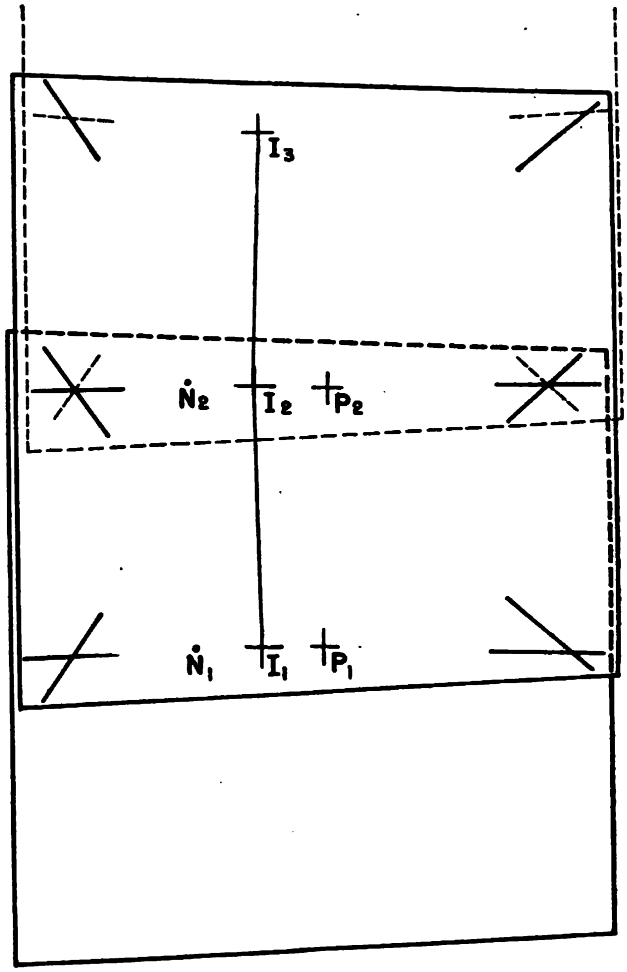


Figure 14. Establishment of positions by radial-line triangulation with tilted photographs.

44. Control Requirements

a. GENERAL. To provide a base upon which to scale the radial-line plot and to maintain that scale, it is necessary to establish or recover certain ground control in the area to be mapped. Since radial-line mapping is primarily planimetric mapping, horizontal control is required. This ground control is used as a base to establish the intermediate

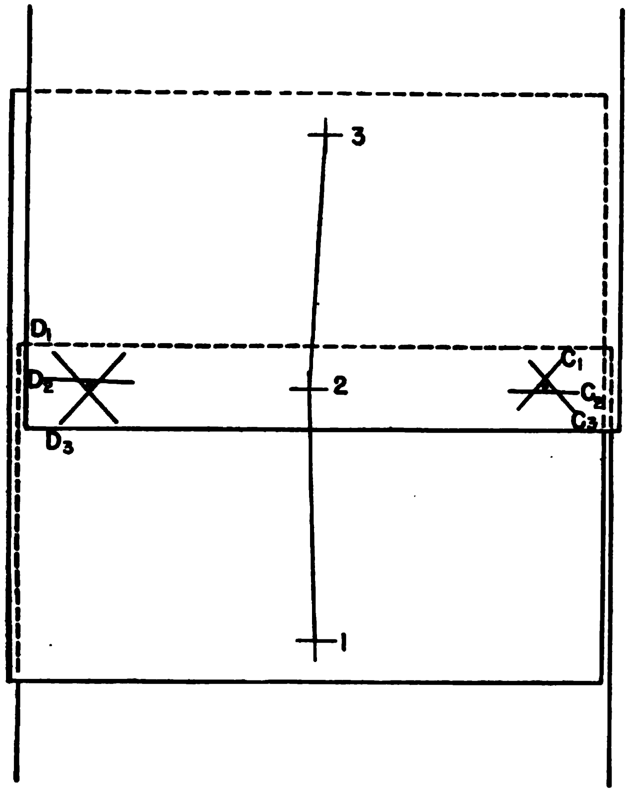


Figure 15. Triangles of error.

network of control points by radial-line triangulation. New control should be kept to a minimum consistent with the accuracy desired in the map. Radial-line mapping is frequently undertaken to produce a reconnaissance map to fill an immediate need for terrain intelligence of an area of which no maps, or only poor maps, are available. In such a case, maximum use must be made of any existing control which can be readily identified upon the photographs. In some cases this type map must be produced with only a limited amount of control, or no control. In the latter situation, scale must be based upon the indicated flight altitude of the photograph above the average elevation of the terrain.

b. Horizontal Control. (1) Horizontal control is most advantageous when control lines are run normal to the lines of flight. The interval between control lines depends on ground conditions and the desired accuracy of the map. In military mapping, where securing ground control is time-consuming and difficult, radial-line triangulation can be done with satisfactory results when control exists only at both ends of a long series of flights. In civil mapping, to achieve required accuracy, control lines should be established at approximately every fifth or sixth pair of overlapping photographs.

(2) When establishing new horizontal control, at least two horizontal control points should be located at both ends of each strip of photographs. These points should be spaced as far apart as possible within the initial or final pairs of photographs, to form a strong starting and finishing base. More than two points per strip give a stronger base. When new horizontal control must be established, not much more effort is required to select and incorporate additional points in the traverse line. It is the additional traverse lines which take time to establish, and which should be kept to the minimum consistent with desired accuracy.

c. Vertical Control. Where vertical control is needed for placing contours upon the planimetric base, it should be planned with the horizontal control.

45. Methods of Radial-line Triangulation

a. Hand Method. The radial-line extension of control can be accomplished by hand operation whereby a large strip of transparent base, upon which ground-control points have been plotted,

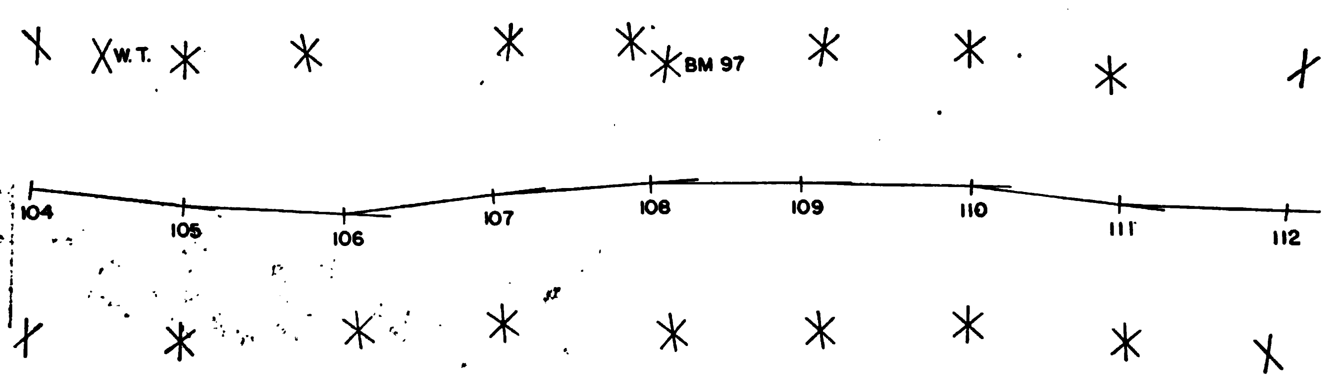


Figure 16. Strip extension by hand method.

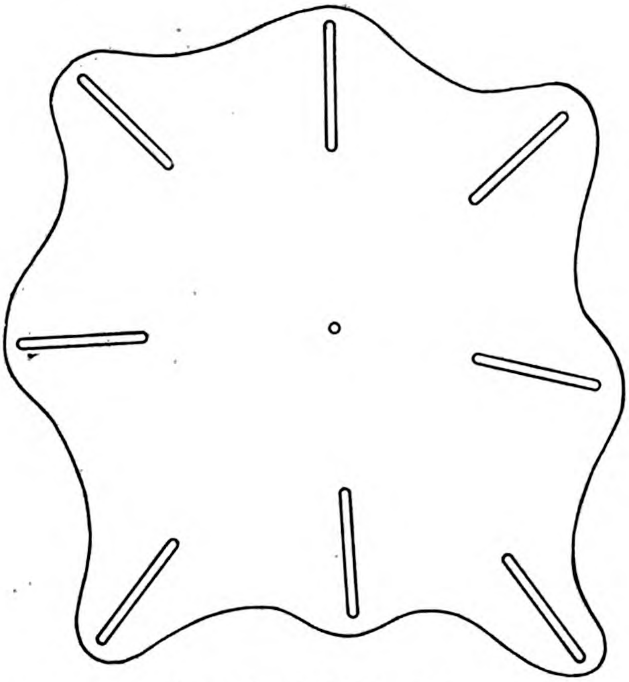


Figure 17. Slotted template.

is oriented to each succeeding photograph in the several strips, and the radials and azimuth lines traced so that the intersections will progress throughout the project. Figure 16 shows a strip extension done in this manner. In another method, individual transparent (ruled) templates are cut for each photograph, the radials and azimuth lines traced on each, and then combined and oriented on the base sheet upon which ground control has been plotted. Templates arranged in this manner will appear as shown in figure 13. Either of the hand methods is a long and tedious process. In mapping large areas neither is efficient.

b. Mechanical Method. The hand method has been improved by mechanical ones permitting large areas to be extended and adjusted with relative ease and permitting mechanical adjustment of errors as well as an efficient means of bridging. One mechanical method is that of the slotted template, pictured in figure 17. Here, the radial intersections are obtained by intersections of the slots, which are held in place by studs of diameter equal to the width of the slots. The center of each stud is hollow, and large enough for insertion of a pin. When a stud is in its correct position on the base sheet, the pin is inserted to prick the location of the point upon the base sheet. A slotted template assembly is pictured in figure 18. A modification of the slotted template method is that of slotted arms. In this method, metal arms are bolted together at

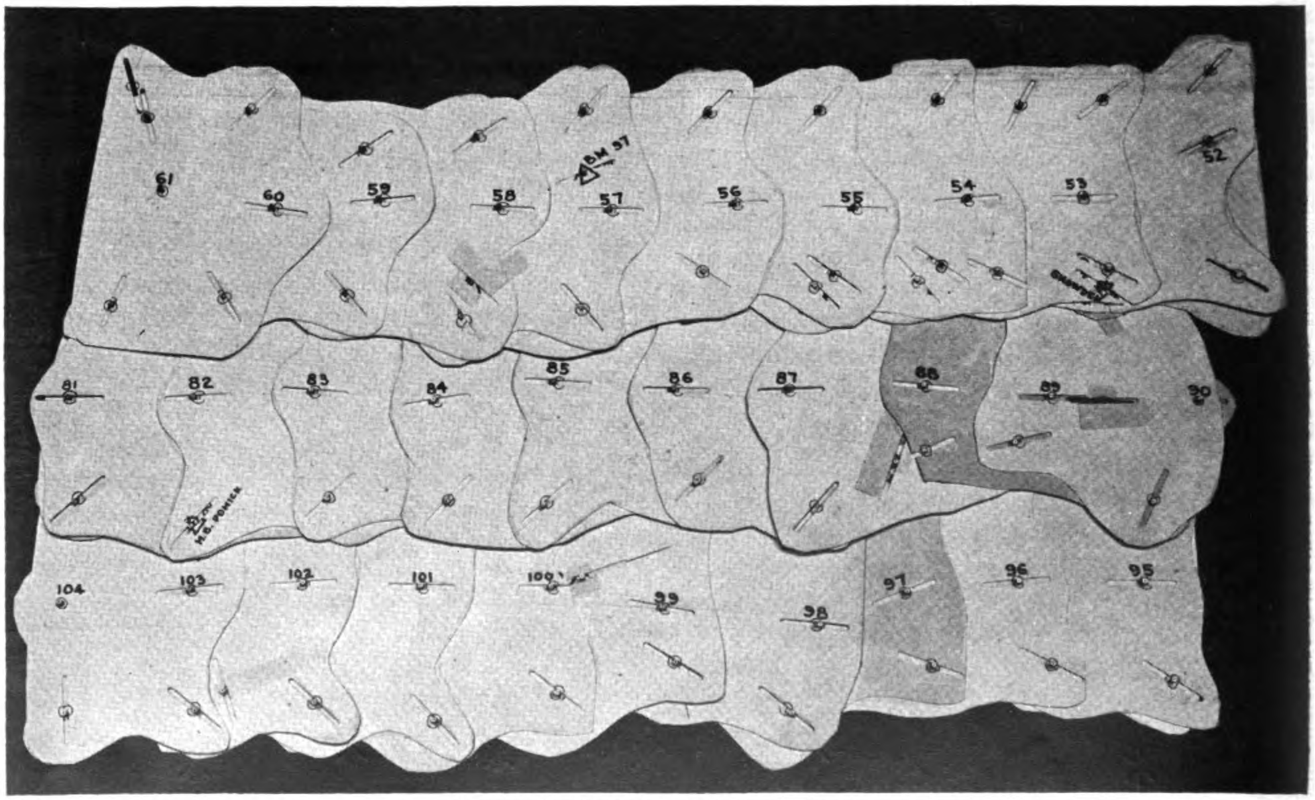


Figure 18. Slotted-template assembly.

the radial center after the center lines of the arms have been made to coincide with the radials on the photograph. A slotted-arm template is pictured in figure 19.

46. Preparation of Data

a. Planning. In mapping with aerial photography the photographic index can be used to afford a means of planning individual operations. This is done by identifying on the index as many control points as possible, plotting the grid lines, and outlining the compilation and publication sheets. With this information assembled on the small-scale picture of the project, each operation can be planned and coordinated. The same index can be used as a progress guide and also as a means of planning the later drafting phases of the project. Its use is necessary in selecting the most logical strips for starting the radial extension. Also, if the work is to be divided into subprojects and distributed between several groups, this index is indispensable.

b. Base Sheet. The projection upon which the control is plotted may be laid out on either an opaque or a transparent base. The type of base will depend upon the size of the project and the method of radial-line triangulation used, but in any case a base having good dimensional qualities is required. Acetate sheeting, having one surface matted, makes a desirable transparent medium. For the radial-line plot the base sheet may be used directly, or the control information may be transferred upon another medium, depending upon the methods to be used in the process.

c. Preparing Photographs. (1) *Arrangements of points.* The ideal arrangement of points on the photographs is as shown in figure 20. It is necessary to select and identify only three new points on each photograph—the principal point and its two wing points. When these are transferred to the overlapping photographs each photograph will contain nine points. Figure 20 shows the numbering of points which correspond to photograph No. 2, whereby points *2*, *2A*, and *2B* are originally identified on the photograph. The other points shown were originally identified on the photograph corresponding to their number, and transferred to photograph No. 2. Points *M1* and *M2* are images on the photograph of ground control points.

(2) *Identification of points.* The first step in identification is to locate the principal points by intersecting lines joining the fiducial marks of the photographs. The principal points are then transferred stereoscopically to the adjacent photographs by point markers described in paragraph 75, TM 5–230. If the identification of the principal point on adjacent photographs is considered unreliable because of the type of terrain, a substitute center is selected as close to the principal point as possible, and this point is used in subsequent operations. When the principal point, or substitute center, is transferred to an adjacent photograph it is called an azimuth point, since it is used in maintaining the azimuth of the radial-line plot. Image points used as wing points or substitute centers should be carefully selected stereoscopically, so as to be positively identifiable on all overlapping photographs. Types of points listed in paragraph 28*b* as desirable for horizontal control are the ones desirable as image points. Transfer of points from photograph to photograph should be made with the aid of a stereoscope, so that correct identification will be assured. Each point selected should be ringed in ink, and numbered on each photograph. The preparation of the photographs amounts only to this selection, transferring, and marking of points.

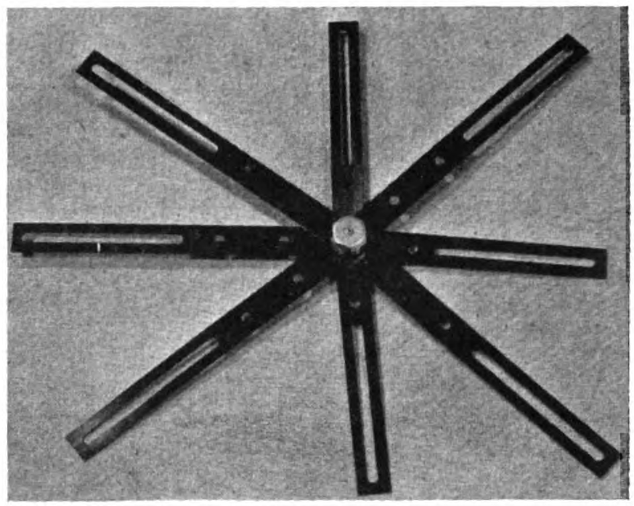


Figure 19. Slotted-arm template.

(3) *Auxiliary intersection points.* In mapping flat terrain by graphical methods, the positions of nine points on each photograph are probably sufficient. Since only those points which are intersected in the radial-line plot are in their true positions, points between them, the elevations of which vary greatly from the elevation of the surrounding intersected points, will be incorrectly located, due

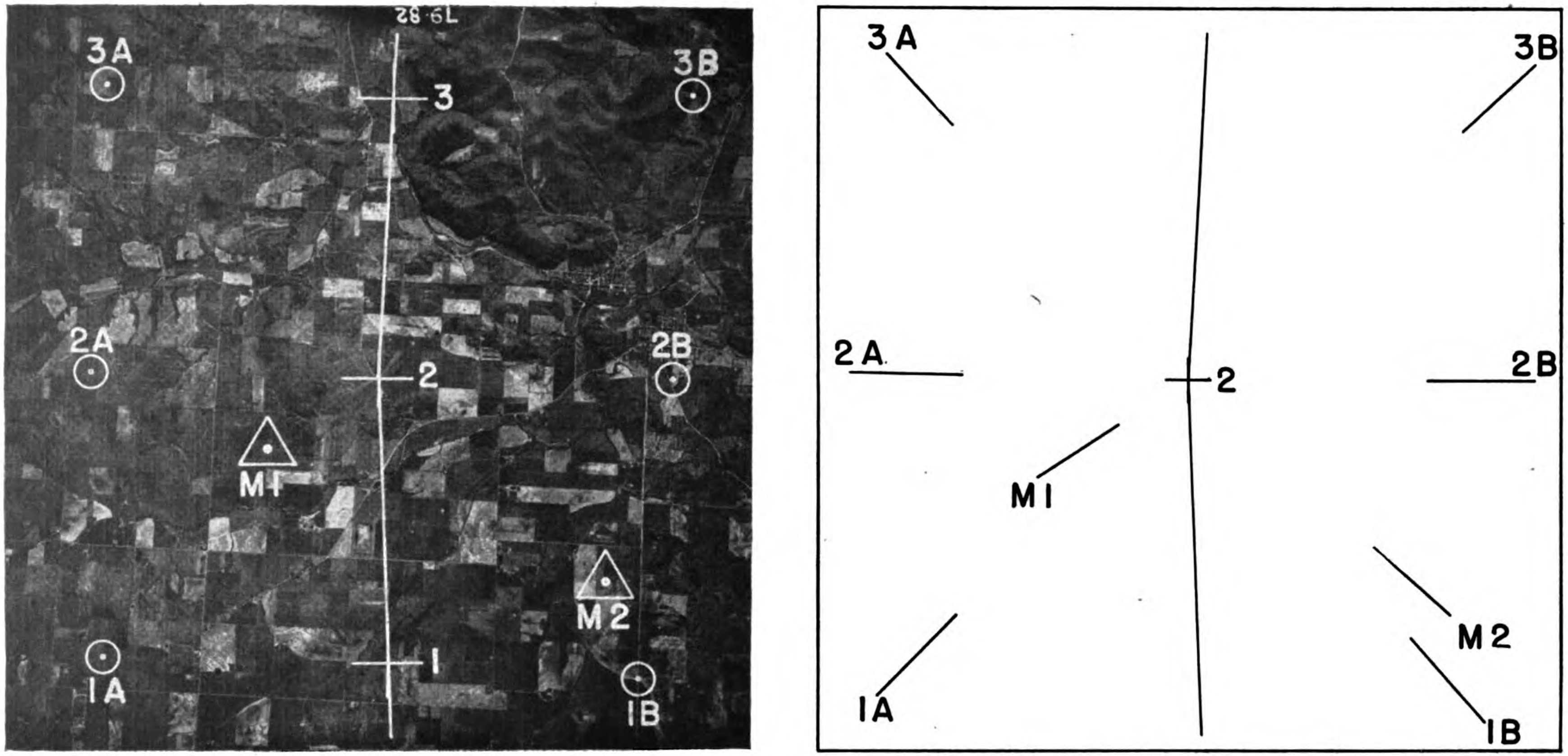


Figure 20. Ideal arrangement of points on a photograph, and appearance of corresponding template.

to relief distortion. To reduce distortion of detail caused by relief, more points need to be intersected where there are great differences of elevation. Obtaining these positions as a part of the radial extension is advisable, if practical, but the practicability depends upon the number of points necessary. When it is large, the establishment of these positions is deferred until after the extension is made. Then, just prior to the plotting of planimetry, the additional points required may be located by reorienting of any two photographs under their respective centers on the base sheet and drawing rays through the desired image points. The two ray intersections will suffice to establish these points. An advantage in deferring this additional control establishment is that the new points are more likely to be selected for their immediate and most practical use.

d. TEMPLATES. (1) *Ruled.* If radial-line triangulation is to be performed by orientation of photographs under the transparent base, no template preparation is necessary. However, radial lines are drawn on the photograph from the principal point through all wing and ground-control points, and through the transferred principal points. In preparing the ruled template, the transparent material (sheet of acetate base) is placed over the photograph, and the principal point is pricked on it. A line is then drawn connecting the principal point with the ones transferred from the adjacent photographs to be used as azimuth lines. Radial lines are also drawn through the wing points and ground-control points so that the finished, transparent, ruled template appears as shown in figure 20. Each radial should be marked to insure correspondence in the radial extension.

(2) *Slotted.* Slotted templates are prepared by use of a slot cutter. Azimuth points and wing points are pricked through each photograph onto a cardboard template beneath the photograph. The pin holes are circled so that they may be easily recovered. The principal point of each photograph is punched, and this hole is placed over the radial center of the slotter, where the slots are punched by using the needle holes as guides. The result is pictured in figure 17.

(3) *Mechanical arms.* In the slotted-arm method the radial lines are replaced by mechanical rays. The slotted-arm assembly is made by placing pins in the photographic print through studs at all wing, azimuth, and control points through which radial lines are desired. Another stud is placed at the principal point, with a pin through its hollow shaft into the photographic print. Slotted arms of the correct length to extend from the principal point to each of the other points are chosen and placed over the studs and pins indicating the respective points. The mechanical arms then are fixed in position by tightening a nut on the stud at the principal point.

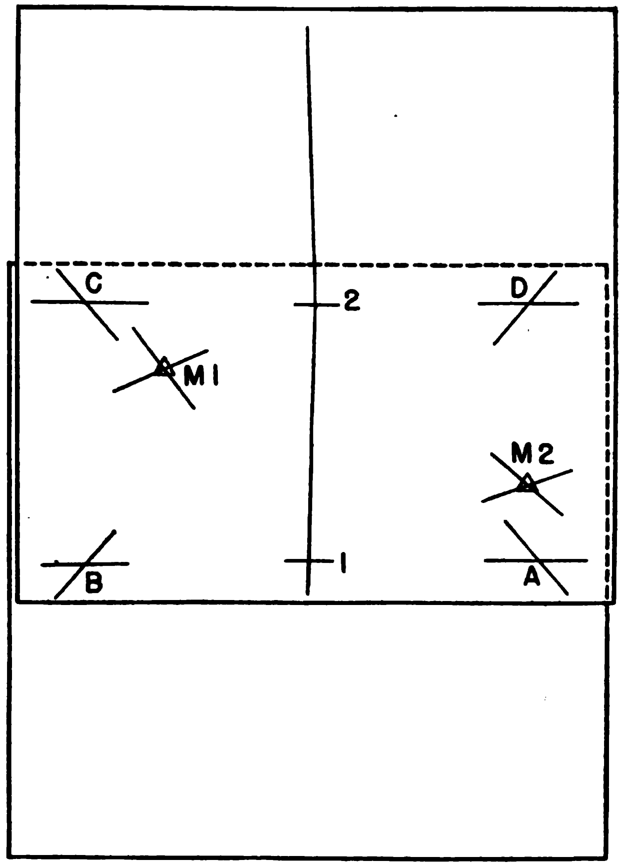


Figure 21. Orientation of first two templates to control.

This mechanical-arm template, shown in figure 19, is used in much the same way as the slotted template.

47. Radial-line Plot

a. PROCEDURE WITH CONTROL. (1) Regardless of whether the radial extension is to be made graphically or by the template method, the projection or base sheet is prepared as the first step in compilation. The most desirable scale to use is that of the photographs, but the nearest even one to that scale is normally used. If the extension is to be made by hand extension, using no templates, it should be made on separate trans-

parent strips. The control points only should be transferred from the base sheet to these strips. Then the extension is made between the bands of control and adjusted to them, after which the overlays are reoriented over the base sheet and the points of radial intersection pricked on it.

(2) When templates are used no overlays are needed, since the templates themselves form the extension. The templates, whether ruled, mechani-

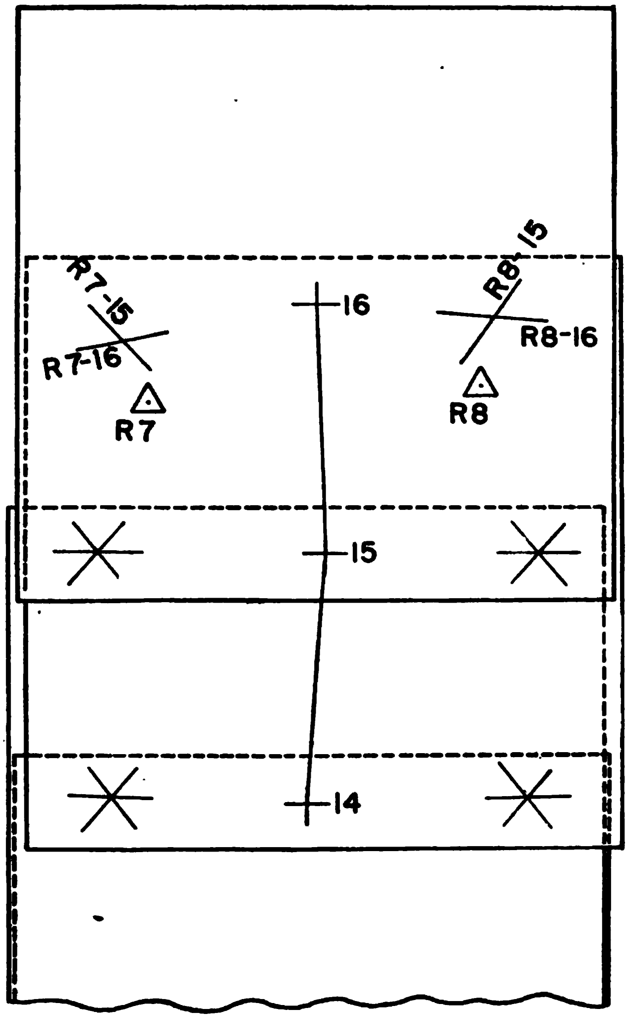


Figure 22. Typical misfitting of control after radial extension.

cal-arm, or slotted, are adjusted in the same manner, between the bands of control, after which the intersections are pricked on the base sheet, accomplishing the same result as the graphical method. In any radial-line system the first two photographs or templates which include control points are oriented and adjusted to the control. Figure 21 shows the orientation of the first two templates so that the rays intersect on the two ground-control points M1 and M2. This establishes the scale of the extension. Succeeding templates are oriented progressively until further control is reached. When this occurs, the errors accumulated throughout the extension are shown by lack of agreement between true positions of control and the positions located from the extension. Figure 22 illustrates a typical finish to an extension where an adjustment is necessary to bring the ray intersections into agreement with the plotted control.

(3) The adjustment of created positions to true position is relatively simple with the use of mechanical templates. The entire series of templates are moved in the desired direction so that the scale is expanded or contracted simultaneously throughout the strip or its parts, without destroying the intersections and flight direction.

(4) When the ruled template or the graphical method is used, a graphical adjustment to control is necessary. Using ruled templates, when the adjustment to control is made, each intersection point is pricked through from the overlapping templates to the base sheet. Using mechanical templates, pins are inserted in the studs when in their adjusted positions, and tapped so that the pin points are recorded on the base sheet. In either method of transferring points to the base, the pin points are circled for ease in recovery and are labeled to correspond with the name or number of the point on the photograph. When the templates are removed and the pin points are circled, the base sheet will appear as shown in figure 12.

b. Procedure Without Control. Radial extension without control is done by making the initial orientiation of the first two templates or photographs equal to the scale of these photographs. These are oriented together, so that the lines joining their principal points are as close to coincidence as possible. Thus the intersections of the forward wing points establish the scale of the extension. Since no control exists, the objective is accomplished when the extension is completed in the forward direction and when the several strip extensions are tied together.

48. Plotting Planimetry

a. Compilation Sheet. The base sheet now has all radial-line control, as well as ground-control positions, plotted upon it. The next step is to compile the planimetric detail. To expedite this work on a large project it is usually divided among a

large number of men. If the base sheet is transparent, it may be cut into several compilation sheets so that several draftsmen may do the plotting simultaneously. The sheets are reassembled for reproduction. Another method with a transparent base sheet is the use of additional transparent material. Control is traced upon the secondary transparent sheet, usually of poorer material. This is then used in the compilation. When an opaque base is used, if the project is large enough to divide among several draftsmen, separate compilation sheets must be used. Upon each the control has been traced or transferred.

b. Sketching. After the system of control points is established, if the scales of base sheet and photograph are nearly the same, any individual photograph may be oriented under the transparent compilation sheet so that any three or more points on the base sheet coincide with the corresponding points on the photograph. When the orientation is made, planimetric features may be traced directly, after which a new orientation is similarly made over neighboring points. Usually the three points cannot be made to agree exactly. In this case one point is placed in correct orientation and the detail immediately surrounding the point is traced. The base sheet is then moved in small steps, and detail is traced after each movement. This is done until another point coincides with its control. In shifting the base sheet, the ray to the principal point from the portion being traced must be kept in coincidence with the corresponding ray of the photograph, since all relief and tilt distortions are assumed radial from the principal point (approximation for small tilts). The process is repeated until the entire area is completed. It can be seen that ease in orientation of photographs containing great amounts of relief depends on the number of points or the size of the area to be sketched in one orientation. When difficulty in this process is encountered, auxiliary intersection points are necessary, as explained in paragraph 46*c* (3).

c. Plotting When Scales of Base Sheet and Photographs Differ. When variations in scale between the base sheet and the photographs are greater than 5 percent, or if great relief is present in the area being mapped, the direct-sketching method is not feasible. Plotting may then be done with a pantograph, a ratio projector, or a vertical sketchmaster, all of which also may be used when plotting at the scale of the photographs. The use of the vertical sketchmaster is discussed further in section VII. The procedure in using any of these instruments is similar, in that the scale ratio of the instrument is changed and the base sheet is adjusted until three points on the photograph coincide with the corresponding plotted points. Detail then is sketched as before.

49. Checking

When the plotting of planimetry is completed, the manuscript should be checked upon if the use of the map and the time available make it possible. Since in military operations the knowledge of all planimetric features is vital, the completeness of the map should be inspected carefully. Some editing should be done, such as classifying roads and streams and adding name data, boundary lines, and other supplemental information obtained from other existing maps.

50. Drafting and Reproduction

a. After the manuscripts have been checked, they are made ready for the final drafting which precedes reproduction. First, however, if the compilation was performed on many individual sheets they are assembled into publication sheets. If the compilation was done on a large sheet, either transparent or opaque, and if there is more than one publication sheet, the large sheet is divided into publication sheets.

b. If the reproduction is to be in colors the compilation sheets may be left in black pencil, and copied photographically. Enough blue-line copies may be obtained for color-separation drafting by contact from the negative. A metal-mounted, or double-mounted, drafting base is normally used for the blue-line copies. Scale of the copy negative will depend upon the publication scale. It may be at the same scale as that of the manuscript, and reduced in the final reproduction after drafting; or it may be at a reduced scale, with little or no reduction in the final reproduction. While advantages may be found in both methods, the former is generally most desirable if the ratio of compilation to publication scale is not too great, since opportunity is afforded to compensate for drafting errors.

c. Final ink drafting on the blue-line copies is done in accordance with standards outlined in TM 5–230. The information to be shown on the respective color-separation sheets is inked in black. Marginal information is placed on the sheet to be reproduced in black. If the reproduction is to be

in one color, detail from the compilation sheets is transferred photographically or graphically to a metal-mounted or double-mounted drawing base, upon which the final inking and titling are performed. After the inked publication sheet or sheets are copied photographically to the publication scale, the resulting negatives are ready for final reproduction. This last step may be performed by either blue printing or lithography.

51. Accuracy

The accuracy of radial-line mapping depends upon the method of radial extension used, the number of strips in the project, the ground control available, the character of the photography, and the care with which the work is done. It is impossible to evaluate all these factors quantitatively and to determine the effect each will have on resulting accuracy. However, for single-strip extension the graphical method or ruled template method is more accurate; while for a large project consisting of many strips, one of the mechanical template methods is best. The slotted template is somewhat more accurate than the slotted arms because of the greater rigidity of the templates. When the slotted-template method is used in a large project, its accuracy will be approximately 1:500 of the distance from control, provided the detail is not too hastily compiled. The greater the amount of control the greater will be the accuracy of the resulting map, except as it is necessarily limited by drafting accuracy.

SECTION VII

MAPPING FROM TRI-METROGON AERIAL PHOTOGRAPHY

52. General

a. Definition. Tri-Metrogon aerial photography is taken with a Tri-camera installation in which three K–17 cameras with 6-inch cones and Metrogon lenses are used. One camera is mounted so that its optical axis points vertically downward, and two cameras are mounted so that their optical axes incline at approximately a 60° angle with the vertical, one pointing to the right and one to the left. The focal plane frames of all three are parallel to the axis of the aircraft. This mounting provides for an overlap of approximately 14° between the fields of coverage of oblique and vertical cameras. With the aircraft in level flight, the oblique cameras cover approximately 7° above the true horizon. All three cameras are interconnected so as to make exposures simultaneously and thus cover a strip of ground extending from horizon to horizon in a direction normal to the flight line.

b. Installation. (1) Generally, Tri-Metrogon installations are fixed, with the cameras secured to the frame of the aircraft. There is a constant angular relationship between the cameras as long as none of them are disturbed; but it does not necessarily remain the same from day to day; it may even change in the course of a single flight, possibly by the replacing of a magazine on a camera. The methods by which the camera mounts are constructed and the cameras set in the mounts do not lead to precision settings. Thus, the angle of 60° to which the oblique cameras are nominally set may be one, two, or more degrees in error. The other angles of setting—the horizontal direction of the optical axes, and the rotation of the cameras about their optical axes—may likewise differ by one or two degrees from the desired setting. Some of the installations require that the cameras be reset by a bubble and protractor every time they are used; this setting will not remain a constant for any given camera and mount. The settings of cameras can be determined only by direct measurement on the photographs obtained.

(2) Although most Tri-Metrogon installations have a rigid connection between cameras and aircraft, this is not always the case. For instance, the vertical camera may be mounted on the floating suspension provided for the usual type of photography. This camera may be manually controlled to maintain it in a vertical position throughout the small variations of the aircraft from level flight. The two oblique cameras may be mounted adjacent to each other on a common framework which, in turn, may be mounted at some other point in the aircraft. In such an installation the angular relationship between the vertical camera and the oblique cameras will change from exposure to exposure.

c. Camera Failures. For normal procedure in Tri-Metrogon mapping, all three cameras are exposed simultaneously. Occasionally, the exposure of one camera will lag behind the others, or one camera will fail to trip at one exposure. The photographic crew should be asked whether any camera failures are known to have occurred, and the photography should be checked carefully for such failures. If failures are found, the procedure should be altered to minimize their effect.

d. Use. Tri-Metrogon photography is used primarily for reconnaissance mapping or for preparing small-scale charts of undeveloped country. It is also of some value in preparing tactical maps if flights have been spaced close enough together so that it is not necessary to compile from the oblique photographs beyond the point at which identification of detail can be made satisfactorily. This distance is roughly the width of another strip of vertical exposures. Where only Tri-Metrogon photography is available at the time a map is desired, maximum use must be made of it.

e. Advantage of Tri-Metrogon Photography. The advantage of this type of photography is its greater ground coverage, permitting a wider spacing between flight lines and less flying. Flying need not be as precise as for vertical photography. It affords a relatively simple and quick method of compiling small-scale charts of undeveloped country.

f. Disadvantage of Tri-Metrogon Photography. This type of photography is not advantageous for mapping at scales larger than required for small-scale charts. When compared to vertical photography, the over-all time for mapping is longer if equivalent scales, accuracies, and amounts of detail are considered. Many more operations must be performed by the mapping personnel in plotting the information from the oblique photographs, and the time is proportionately increased. At the ordinary spacing of Tri-Metrogon flights, sufficient detail cannot be recognized on the oblique photographs for tactical mapping or even for small-scale charts if the terrain is well developed.

53. Control

a. General. The control requirements for mapping with Tri-Metrogon photography depend upon the accuracy desired in the map and the time available. Probably most mapping done from this type of photography will be with little or no control.

b. Density. Where a map of a required accuracy is to be prepared from Tri-Metrogon photography, the density of ground control required is somewhat greater than that required for the radial-line method and vertical photography. This is because the tie between flights when using Tri-Metrogon photography is not as rigid as between flights of vertical photographs.

54. Principles of Mapping from Tri-Metrogon Photography

Since the Tri-Metrogon assembly is a vertical camera combined with two oblique cameras, the method of mapping from such photography must combine mapping from vertical photography with mapping from oblique photography. To understand the methods used, a knowledge of the geometry of perspective projections is required. This is discussed in section V. The methods employed are partly analytical and partly graphical. First, it is necessary to determine the constants of the camera settings, such as the angular relationships which each camera bears to the other cameras and to the vertical (tilt of camera). These constants serve as the basis for determining true directions from the plumb points. Once the true directions are found, the principles of the radial-line method are used to resect points for use as an intermediate-control network in plotting planimetric detail.

55. Horizontal Directions

a. Theory. In figure 23 an oblique photograph is represented in the plane $BCDE$. The point O represents the perspective center, or point at which the exposure was made. The point P is the principal point on the photograph and f is the principal distance (focal length of the camera). The vertical line ON is the plumb line, and it intersects the plane of the photograph in the point N, the plumb point. The plane ONP is the principal plane passing through the principal point and intersecting the plane of the photograph in the line NPH.

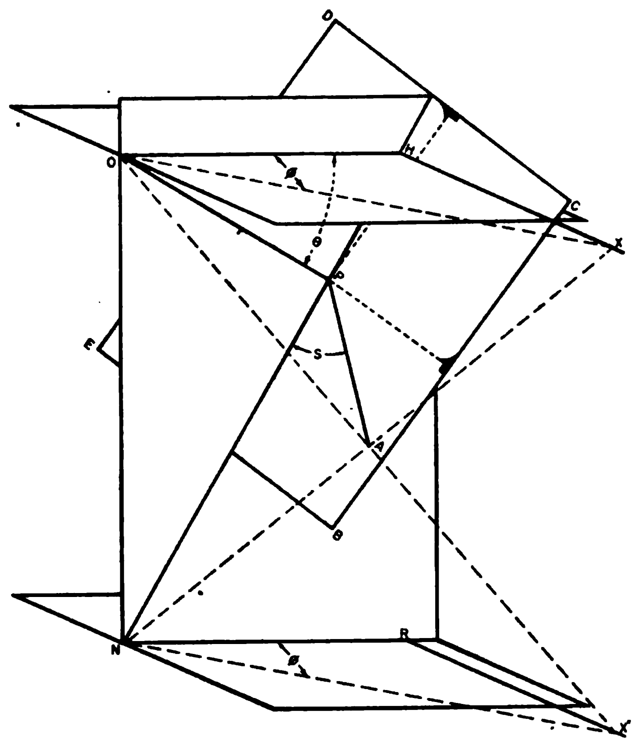
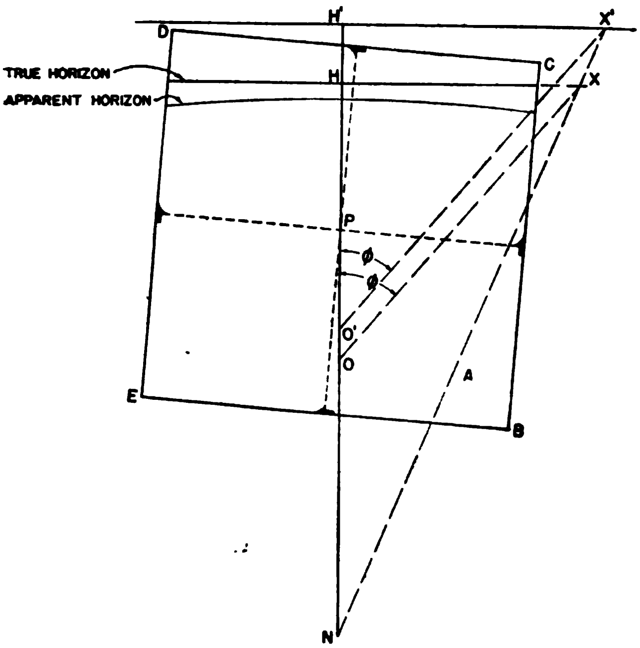


Figure 23. Horizontal direction from oblique photograph.

A horizontal plane through O intersects the plane of the photograph in the line HX, the true horizon line. The line OA is a ray to some point on the ground, and intersects the plane of the photograph at the image point A. The position of A on the photograph is defined by the distance PA and the angle S from the principal plane. A vertical plane OXN passing through the point O and the point on the ground contains the image point A, and intersects the plane of the photograph in the line NAX. The angle RNX' is the angle between the principal plane and the vertical plane containing O and A, and is called the horizontal direction of the point A. Angle HOX is equal to angle RNX', and is called ϕ in the figure. It is seen that

ϕ is dependent only upon the tilt of the photograph θ, the location of the image point with reference to the principal plane, and the focal length of the camera. When these factors are known it is possible to determine the value of the horizontal angle at the plumb point to any desired point.

b. METHODS. (1) *General.* Various means are all dependent on the basic relations shown in the equations accompanying figure 24, available to determine horizontal angles from oblique photographs. All methods require that the tilt, position of the principal plane, and the accurate focal



$$PN = f \cot \theta \quad PH = f \tan \theta \quad OH = \frac{f}{\cos \theta} \quad O'H' = NH' \sin \theta$$

$$\cot \phi = \left[\frac{f \cos \theta}{PA} - \sin \theta \cos S\right] \Big/ \sin S$$

Figure 24. Horizontal direction in plane of photograph.

length of the camera be known. The fundamental method of determining horizontal angles is by measurement directly on the photograph of the quantities PA and S, and computation of the horizontal angles from the relation shown.

(2) *Graphical method.* Horizontal directions are readily obtained by a graphical solution, since it is seen from figure 23 that a line from N through A intersects the horizon line in the same point X as the horizontal direction line from O. By rotating the horizontal plane around HX so as to bring O into the plane of the photograph, the construction takes the form shown in figure 24. The construction lines then may be laid out on tracing paper with the distances OH, PH, and PN computed from the simple relations shown. By placing the tracing paper over the photograph, radial lines from N then may be drawn through desired image points to establish intersections with the horizon line HX. Radial lines from O to these intersections then give the desired horizontal directions. Although other graphical methods are possible, it is believed that the method illustrated is desirable, as it permits easy computation of the distances required and permits a convenient arrangement for reducing drafting errors.

(3) *Angulator.* The angulator solves the problem of horizontal directions in much the same manner as the graphical solution described above. By placing mechanical arms to represent the lines drawn in the graphical method, and by providing certain mechanical linkages, the time required for obtaining the directions is considerably lessened. Instead of using the true horizon line in the solution, the angulator is based upon a line above and parallel to the true horizon. Such a line is illustrated in figure 24 as $H'X'$. It is seen from the illustration that such a line may be used if the center of horizontal directions is shifted from O to O'. Shown with figure 24 is the additional relationship required to determine the distance $O'H'$, and hence to locate the position of O'. It is seen that $O'H'$, depends only on the tilt θ, and the distance NH'. By construction, the distance NH' as represented on the angulator is constant, and so O' depends only on the tilt. The general layout of an angulator designed for a nominal focal length of 6 inches and a normal tilt of 30° from the horizon is shown in figure 25. Figure 26 is a photograph of the device set up for operation. It is noted in figure 25 that the arm representing the line $O'X'$ has been moved to right and downward, to obtain drafting space. It is then connected to the arm representing NX', so that the proper relationships are maintained. Scales are provided for locating the principal point of the photograph on the angulator and for adjusting the distance $O'H'$ to the proper amount. It is still necessary to know the focal length of the photograph, its tilt, and the location of the principal line, to set the photograph properly on the angulator.

c. EFFECT OF ERRORS. (1) *Maximum direction errors.* The effect of errors in the tilt θ, the position of the principal plane as established by the angle S, and the focal length f, on the hori-

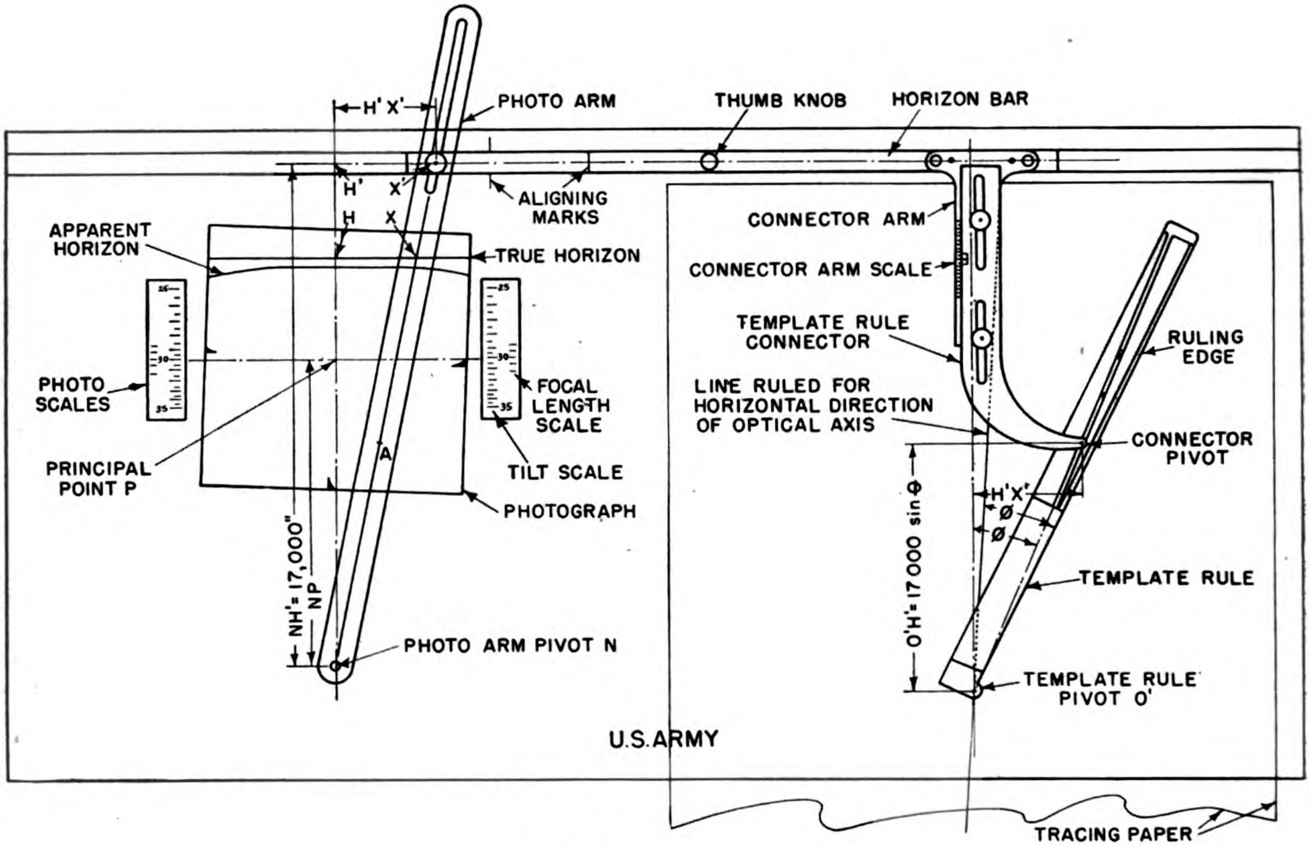


Figure 25. Layout of angulator.

zontal angles extracted from the oblique photograph, are given by the differential equation:

$$d\phi = \sin^2\phi\left[\left(\frac{f \sin\theta}{PA \sin S} + \cos\theta \cot S\right)d\theta + \left(\frac{f \cos\theta \cos S - \sin\theta}{PA \sin^2 S \sin^2 S}\right)dS - \left(\frac{3438 \cos\theta}{PA \sin S}\right)df\right]$$

when $d\phi$, $d\theta$ and dS are in minutes and df, f and PA are in millimeters. The effects of errors in these factors on the horizontal angle are greatest when the horizontal angle is greatest. This occurs for image points in the lower corners of the photograph. In the case of the oblique photographs this maximum horizontal angle measured from the principal plane is approximately 56° 40′. For points in this position, the errors $d\phi$ in the horizontal angle due to errors $d\theta$ in the tilt, dS in the swing of the principal plane, and df in the focal length, are as follows:

$$d\phi = 1.08\ d\theta$$
$$d\phi = .11\ dS$$
$$d\phi = -18.15\ df$$

where $d\phi$, $d\theta$ and dS are in minutes and df is in millimeters.

(2) *Normal direction errors.* The normal case does not require using the oblique photographs to such wide angles. The overlap of obliques with verticals and the overlap in the line of flight, generally makes it unnecessary to use image points on the oblique photographs closer than 1½ inches to the bottom edge and 1 inch to the side. A point at this location has a horizontal angle of approximately 43°25′, and the errors in this angle due to the errors in tilt, swing, and focal length, are as follows:

$$d\phi = .76\ d\theta$$
$$d\phi = .19\ dS$$
$$d\phi = -15.88\ df$$

where $d\phi$, $d\theta$, and dS are in minutes and df is in millimeters.

(3) *Effect of tilt errors.* It is seen from the above examples that the tilt used for oblique photographs is the most critical factor affecting the accuracy of the horizontal angles. It will be shown later that this is further so since the tilt is more indeterminate in the methods employing Tri-

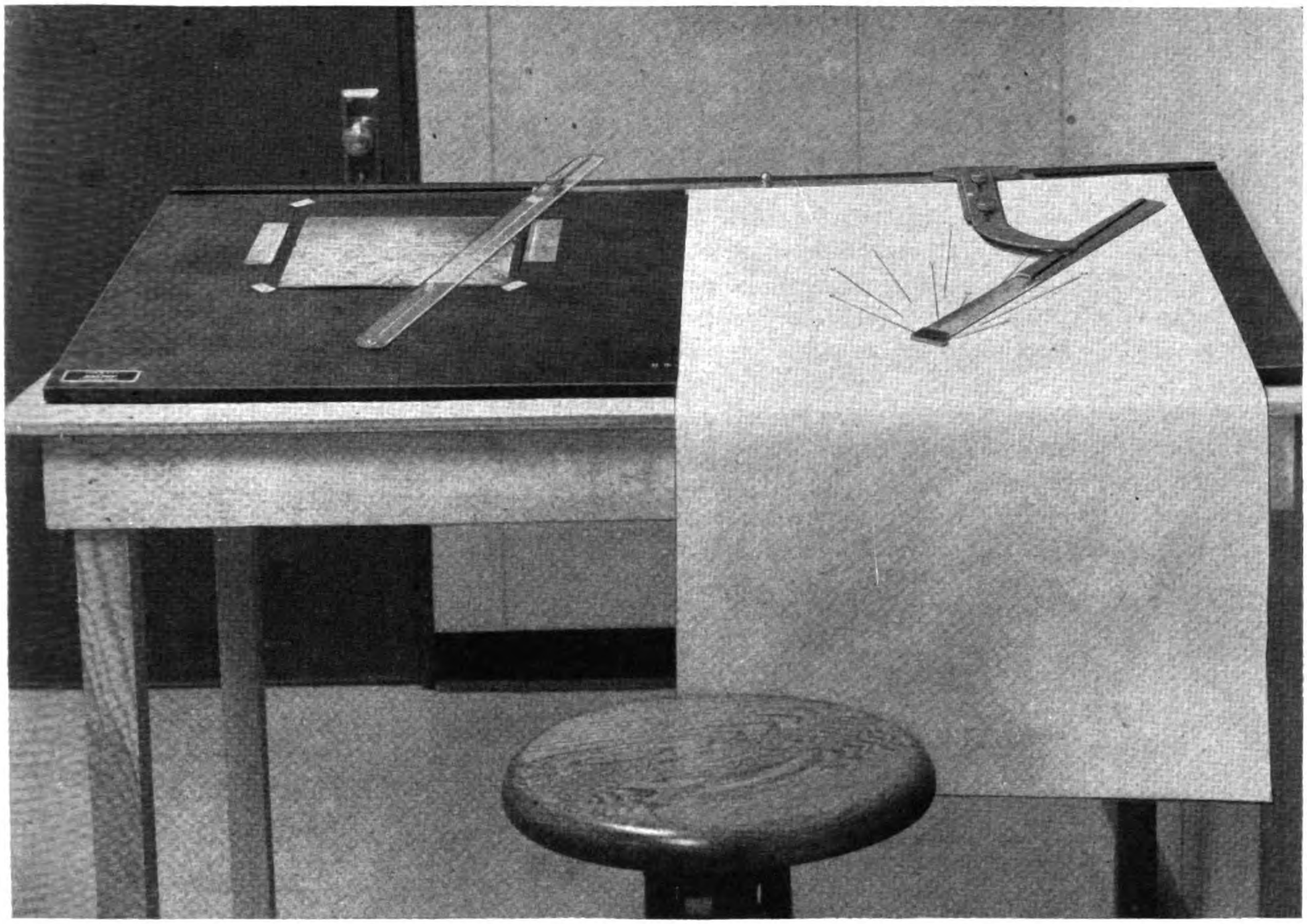


Figure 26. Angulator set up for use.

Metrogon photography than the swing and focal length.

(4) *Lens distortion.* Distortion present in Metrogon lenses also will affect the accuracy of horizontal angles obtained from oblique photographs. This lens has appreciable distortion which will cause an error of 3 or 4 minutes to occur in the horizontal angles obtained between points at extreme, opposite corners of the oblique photograph, and will cause an error of 2 or 3 minutes in the horizontal angle obtained between a point in an extreme corner and a point approximately 2 inches in from the corner. Although it is possible to calibrate the lenses and to apply corrections for this distortion, the relatively small size of errors makes it unnecessary.

(5) *Paper distortion.* Distortion resulting from uneven shrinkage or expansion of the paper on which the photographs are printed will also cause errors to occur in the horizontal angles. It is difficult to evaluate such possible errors but with improper processing of prints it can become quite large. If there is a large, uniform change in the size of the prints after processing, it will change the principal distance (focal length) of the print. This will have the same effect on the horizontal angles as errors in focal length, and can be compensated for by adjusting the focal length according to the shrinkage or expansion that occurs.

56. Determination of Camera Settings

a. General. The relative orientation of the cameras—camera setting—in a Tri-Metrogon installation may be determined from measurements on the photographs. Thus, if the tilt of one camera is known or can be determined, the tilt of the others may be determined through the relative setting. Or, if the relative orientation of each of the obliques with respect to the vertical is determined, the relative orientation of the two obliques with respect to each other may be computed. To compute the camera settings, the accurate focal length of each camera must be known. This is the focal length marked on the lens-retain-

ing ring in millimeters and not the nominal focal length of the lens.

b. Angles Required. Illustrated in figure 27 are the vertical and one of the oblique positive prints of the Tri-Metrogon assembly. These show the relationship it is necessary to determine for the two cameras. Since it is assumed that all the cameras expose their negatives from the same point, figure 27 represents both cameras having the same perspective point at *O*. The focal lengths, f and f_R, and the location of the principal points, P and P_R, are known for the cameras involved. It is necessary to determine the angle β_R between the principal axes of the two cameras and the angle δ_R between the direction of the oblique principal axis when projected into the plane of the vertical exposure and the line between fiducial marks on the vertical exposure. This angle δ_R has no significance in itself, but determines the angles between the directions of the two oblique cameras. The difference in the values of δ_R for the right oblique and δ_L for the left oblique is the angle between the directions of pointing of the two oblique principal axes when projected into the plane of the vertical exposure.

c. Line of Intersection. To determine the angle β_R it is necessary first to locate the intersection of the plane through the two principal axes with the planes of the two photographs, since that is the plane in which the angle must be measured. This is located best by finding the intersection between the planes of the two photographs, the line AB in the illustration. Then the perpendiculars from P and P_R to the line AB will be lines of intersection of the planes of the photographs with the plane containing two principal axes. These perpendiculars will intersect the line AB in I_R. Then the tangent of the angle β'_R is determined by the relation $\frac{PI_R}{f}$ and the tangent of β''_R by $\frac{P_RI_R}{f_R}$. It is seen then that $\beta_R=\beta'_R+\beta''_R$ and is the angle sought. Also, the location of the point I_R on the two photographs locates the lines PI_R and P_RI_R, and permits measurement of the angles δ_R and δ'_R, thus determining all the relations

$$\alpha' = \tan^{-1}\frac{PA}{f}$$

$$\alpha'' = \tan^{-1}\frac{P_RA}{f_R}$$

$$OA = \frac{f}{\cos\alpha'} = \frac{f_R}{\cos\alpha''}$$

$$\beta'_R = \tan^{-1}\frac{PI_R}{f}$$

$$\beta''_R = \tan^{-1}\frac{P_RI_R}{f_R}$$

$$\beta_R = \beta'_R + \beta''_R$$

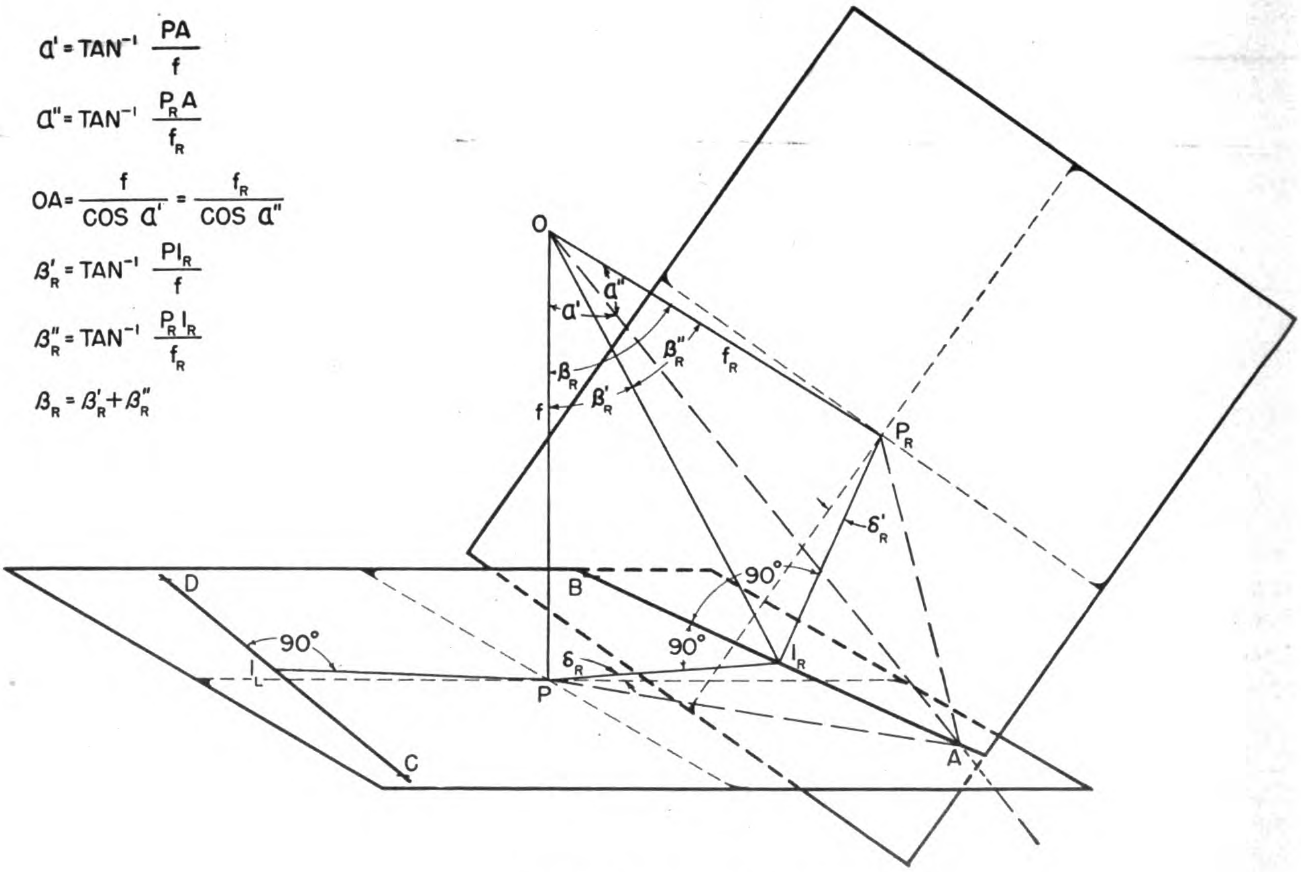


Figure 27. Camera settings.

which define the relative settings of the two cameras.

d. METHOD. (1) The position of the line of intersection AB of the two photograph planes is most readily established by trial and error. Near the midpoint of the overlap of the vertical and oblique exposures, and as near the edge of the exposures as possible, some definite photographic image is selected. This image on both exposures then represents the intersection of the planes of both photographs with the ray from O to the feature on the ground. Such a point is represented by A. PA and P_RA are measured on the two photographs. Then the angles α' and α'' are found from the relations $\tan \alpha' = \frac{PA}{f}$ and $\tan \alpha'' = \frac{P_RA}{f_R}$. Then the values of α' and α'' are used in the relation $\frac{f}{\cos \alpha'} = \frac{f_R}{\cos \alpha''}$. If the values of α' and α'' satisfy this equality, then A is a point on the line of the two photograph planes.

(2) If the equality is not satisfied, a new position for A is selected and the operation repeated until equality is found. Two or three trials should be sufficient. A point B then is similarly found on the line of intersection at the other end, and the two points are connected by a straight line. A check is afforded by this line drawn on both the vertical and oblique photographs, as it should pass through identical image points on both. Next, a perpendicular is drawn from P and P_R to the line AB as located on the two photographs. This locates the point I_R, and thus the angles β_R, δ_R, and δ'_R may be found. In the same way the line of intersection of the vertical photograph with the other oblique is found as shown in the line CD, the perpendicular from P locates I_L and the angle β_L is determined for that oblique.

e. APPROXIMATE METHOD. When the focal lengths of the two cameras are about the same, the camera settings may be determined accurately enough by locating a line near the line of intersection, and parallel to it, rather than the actual line of intersection. This may be done quite easily by swinging arcs of equal length from the principal points of both photographs through each end of the overlap area, and then locating along these arcs identical images in both photographs. The line between the images is a line parallel to the line of intersection. The angle between the two cameras, β_R, then is determined as before, except that the perpendicular S/P_R and I_R and PI_R are extended, and the distance is scaled from P and P_R to an identical image on both photographs falling on the lines P_RI_R and PI_R or their extension. These distances, divided by the corresponding focal lengths, will give the tangents of the two angles, the sum of which equals β_R.

f. HORIZONTAL ANGLE BETWEEN OBLIQUES. In figure 28 is shown a diagram of the vertical photograph with the two lines AB and CD. When the two angles δ_R and δ_L are combined, as shown in the illustration, the angle obtained is the angle between the directions of the two oblique principal axes as projected into the vertical exposure. If the plane of the vertical exposure is assumed horizontal, the angle then represents the horizontal angle between the directions that the two oblique cameras are pointing. Where greater accuracy is desired, or where the angle of tip in the vertical photograph is excessive, it may be desirable to determine the angle between the direction of the two obliques as projected on a horizontal plane. This angle is approximately equal to

$$\frac{\gamma + 2 \times \text{tip of the vertical}}{\tan \beta_R}$$

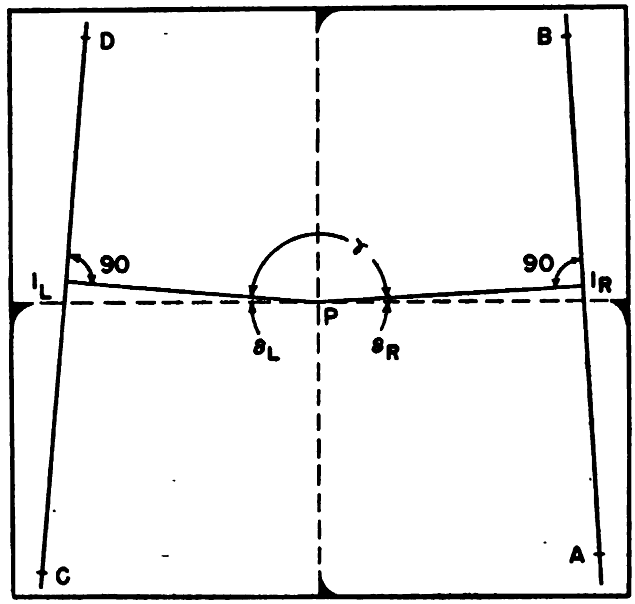


Figure 28. Horizontal angle between obliques.

g. DETERMINATIONS REQUIRED. The frequency with which the relative settings of the three cameras should be determined will depend upon the installation used and the reliability of

the amounts for holding constant relations. Unless experience indicates that greater frequency is required, determinations should be made at least at the beginning and end of every roll of film, and at other points indicated by the record of photography where possible changes may have occurred.

57. Tilt Determination

a. GENERAL. When the axis of the vertical camera coincides with the plumb line, the angle β_R in figure 27 between the principal axes of the oblique camera and the vertical camera is the tilt of the oblique camera. Normally, however, the axis of the vertical camera is not vertical. In the method which follows for mapping with oblique photography the tilt of the oblique photography must be determined. Whether the tilt determined by the camera setting is accurate enough depends upon the manner in which the photography has been flown, the type of installation, and the accuracy desired in the map. As shown in paragraph 55*c*(2), an error in the tilt will cause errors in the horizontal angles of three-fourths the amount of the tilt. With photography from a fixed mount where it is apparent that the angular position of the aircraft has been practically constant, and where the map is to be a small-scale chart or a strategic map, the computation of individual tilts may not be warranted.

b. METHODS. To define the tilt of an aerial photograph, both the inclination of the optical axis from the vertical and the direction of tilt, or the location of the trace of the principal plane on the photograph, must be determined. This may be accomplished by various methods of computation if there is sufficient ground control, properly positioned in the area covered by the photograph, but as this condition seldom occurs in practice these methods are of little practical value. With high oblique photography, the tilt may be determined quite readily from the apparent horizon with a fair degree of accuracy. Where the location of the apparent horizon on the photograph is uncertain, the usual practice is to accept the camera setting as the tilt.

c. USE OF CAMERA SETTINGS. (1) The reliability of the tilt value, as determined by camera settings, depends upon the type of flying and the care with which the cameras have been installed and adjusted to their normal angular setting. When the enemy is active, the pilot cannot maintain the level of the plane accurately, and large variations in tilt can be expected. In determining the tilt value from camera settings, a logical approach should be used, based upon the method used in setting cameras in the installation concerned. For instance, if for each mission the cameras are individually set in their respective mounts by a level bubble and protractor, the oblique cameras being set to an angle 60° from the vertical, the rational method of tilt determination will be to average the three settings. First, assume that the vertical camera was set truly vertical. Second, assume that one oblique camera was truly set to 60° and, from the angle between that oblique and the vertical, determine the direction and amount the vertical camera would be out from the desired vertical setting. Third, assume the other oblique correctly set, and determine the error in the vertical camera. The average of the three positions for the vertical camera should be used for its setting and for computing back to the tilts of the two obliques.

(2) A complete understanding of the method of installation of the tri-camera assembly is essential in determining the tilt values to be used. Personal observation of the installation should be made wherever possible. The tilt value desired is the actual tilt of the oblique camera, measured from the true horizontal when the aircraft is in its normal level flight position. This is the average tilt value of the camera, and hence will introduce the minimum of error.

d. TILT FROM VISIBLE HORIZON. To determine the tilt from the visible horizon, an accurate value of the focal length of the camera, and a fairly accurate value for the flight altitude above the level of the land or body of water which formed the visible horizon, must be known. Figure 29 shows a view in the principal plane of a high oblique aerial photograph. The refracted ray of light from the visible horizon intersects the plane of the photograph at H'. This is called the apparent horizon on the photograph. The true horizon is at an angle D, the dip angle, above the apparent horizon. The true angle of tilt below the horizon, θ, is equal to the angle of tilt below the apparent horizon, θ', plus the dip angle D. For all practical purposes the dip angle in seconds of arc may be taken as equal to 59 $\sqrt{H}$, where H is the flight altitude in feet. Thus, from the figure, $\theta = tan^{-1}\ d'/f + D$. A cloud horizon, or the top of a high range of mountains in the background, must not be selected as the ground horizon. A good check on whether the

apparent horizon is correctly identified may be made by adding the angles, θ, obtained in this manner for the right and left obliques, to the camera settings for the right and left oblique. This sum should equal 180°.

e. Relative Tilt From Visible Horizon. The position of any horizon, ground, cloud, or water, or the top of a mountain range at a great distance, may be of value in determining variations of tilt. Measurements to identical features near the horizon line on a series of exposures of a flight may be averaged to establish the normal position of the camera. The variations from that normal position may be used to compute the changes in tilt and, if the tilt in the normal position is known for other sources, the individual tilts thus may be closely determined.

f. Locating Principal Plane. (1) The horizon image appearing on the oblique photographs is normally definite enough to establish the position of the principal plane. Although it may be a cloud horizon, it will be approximately parallel to the true horizon. The position of the principal plane should be established through the principal point and normal to the apparent horizon. Probably this will, in the value of the swing angle, introduce no error greater than 30 minutes, and usually less than 10 minutes. It was shown in paragraph 55c(2) that the errors in horizontal angles are approximately two-tenths of this error in swing.

(2) It is convenient to prepare a template on film base or transparent tracing paper to aid in marking the position of the principal plane. Two perpendicular lines will serve this purpose, if arranged on the template so that one may be placed approximately over and parallel to the apparent horizon, with the other passing over the principal points. Marks made at the edges of the photographs by pricking through or ruling along the line passing over the principal point will indicate the line of intersection of the principal plane and the plane of the photograph.

(3) When the angulator is to be used to prepare horizontal direction sheets, it is preferable to mark a line perpendicular to the principal line and through the principal point of the oblique, rather than to mark the principal line itself. This may be done readily by adding such a line to the template described above. It is necessary only to mark the ends of this line along the margins of the photograph. This line then is used in setting the photograph on the plotting board of the angulator.

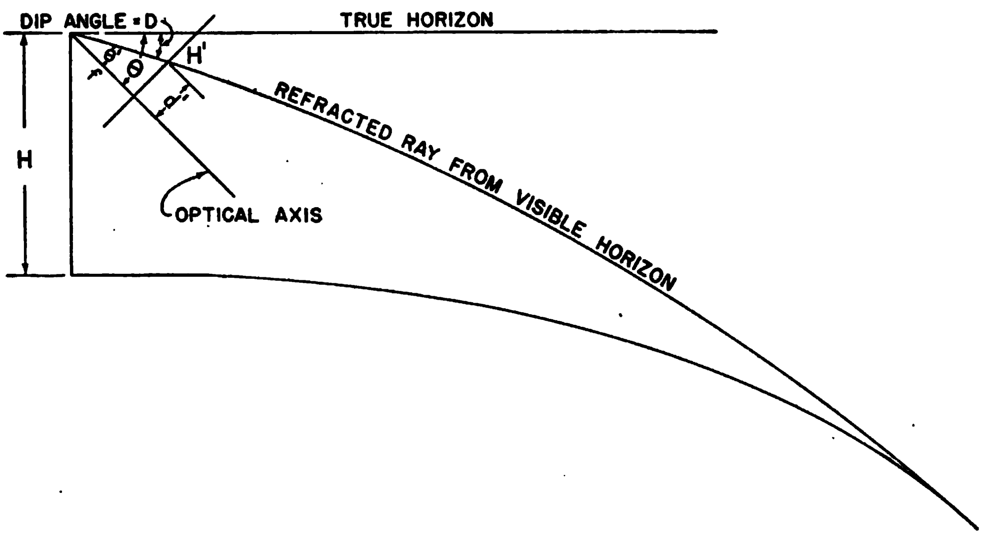


Figure 29. Tilt from visible horizon.

58. Procedure

In the method of producing a map from Tri-Metrogon photography many steps are involved, but they are relatively simple and may be mastered quite easily. Vertical exposures of the Tri-Metrogon assembly are joined in a minor control plot by the radial-line method. Horizontal directions are determined from the oblique exposures so that they may be properly resected and oriented with respect to the radial-line plot of the verticals. From the obliques additional horizontal directions are determined for points midway between flights, using a mechanical type of radial-line system and

these serve to tie the flights together. For control of plotting, additional points lying between flights are located by horizontal directions obtained from overlapping oblique exposures. Detail is compiled from the vertical exposures to the radial-line plot by use of a vertical sketchmaster, a form of camera lucida, or by any method that permits adjustment of detail to minor control points. Detail is compiled from oblique exposures by use of a form of camera lucida known as an oblique sketchmaster. It presents to the eye a rectified view superimposed on, and adjusted to, the minor control points established. The completed compilation is put through the necessary drafting and reproduction steps as for any other mapping method.

59. Photographs To Be Used

a. Normal Photography. As a radial-line plot of the vertical photographs is made in the minor control plot, it is necessary to use all the verticals for this purpose. The actual compilation of detail normally requires only alternate vertical photographs, however. Since the oblique exposures overlap each other 60 percent along the near edge in the direction of flight, and about 80 percent along a line through the principal points, it is normally necessary to use only altenate oblique exposures. Where control points or other points of interest to be located in the minor control plot fall in the foreground of the obliques, it may be necessary to use successive exposures to cover those points. All points located in the minor control plot must appear on at least two exposures. For tactical maps of maximum accuracy all exposures will be required. The necessary prints should be segregated from the remaining ones, to eliminate excess handling.

b. Excessive Overlap. With some types of installation excessive overlap may be obtained along the flights, and it may be necessary to discard additional photographs. The vertical photographs selected should overlap as closely as possible to the 60 percent desired. The obliques that accompany these verticals should be selected. These verticals and obliques then may be considered as the ones obtained had the photography been performed to the desired overlap. They may be treated as in *a* above, and those not selected may be *placed aside*. All future references to alternate exposures will mean the alternates of those selected.

60. Marking Principal Points

As one of the first steps, the principal points of all photographs to be used should be located and marked by connecting opposite fiducial marks with straight lines, or by use of a template. It is convenient to indicate all principal points by circles inked with a drop compass. Next, the locations of the principal points of the vertical photographs are transferred forward and backward where they fall on overlapping exposures, and are similarly marked. Transferring should be done while viewing the areas stereoscopically, and may be aided by a point selector.

61. Minor Control Points

a. Verticals. Minor control points are selected and marked on the vertical photographs as for the usual radial-line method. Nine points per photograph are normally sufficient, the principal points previously marked and transferred serving for three of these points. In addition, all control points and points for which a position is desired in the minor control plot should be identified and marked. The points at the sides of the photographs should be selected as far from the centers as possible, to obtain maximum strength in the plot. The side points should also be selected so as to lie on the oblique photographs and to be identifiable there. They should be marked on the proper obliques at the same time they are selected and marked on the verticals. Excessive crab will make it difficult to select the points along the sides of the vertical photographs so that they will lie on all of the obliques on which they would normally appear. Where this happens, it is not necessary to select additional points, since each oblique is used with the one opposite, and the two will always contain at least four of the points from the verticals.

b. Obliques. (1) Minor control points are selected and marked on the obliques to tie together the successive obliques and the flights. Where a strip of obliques is on the edge of an area to be compiled, the points should be selected along a line approximately through the principal points. Using only alternate exposures, this permits points to be spaced so that three will occur on each oblique. Selecting a point near each principal point meets this condition. At least three points must appear on each oblique and each point on at least three obliques, except for obliques at the ends of flights. These points are circled with a distinctive

colored ink, and are assigned numbers. This aids identification of corresponding rays needed to establish the intersection for the point in later phases.

(2) Between parallel flight lines, minor control points are selected approximately in the middle so as to appear about the same distance out on both sets of obliques. The points selected must be identifiable on both sets, and must be spaced at such an interval that at least three will fall on each of the alternate obliques used. Likewise, every alternate oblique must have three points, each of which appears on two other obliques of the same flight. This condition will be met by selecting a point about on a line midway between flights and about in the center of each of the alternate obliques of each flight. Where oblique exposures are located about opposite each other, one point will usually suffice for both. The points should be inked and numbered as described in (1) above.

(3) In addition to the points selected as described above, all control points should be located on all obliques on which they appear, marked, and given an identifying control designation. To be of value, the control points must appear on at least two obliques. To obtain this condition, it may be necessary to use an oblique in addition to the alternate ones. Other points to be located in the minor control plot may also be marked on the obliques and properly identified. All points described above for both verticals and obliques will be referred to hereafter as "minor control points" to differentiate them from the points described in the following paragraph.

(4) Additional points are selected on the obliques to control the compilation in much the same manner as a great number are selected for a detailed compilation by radial-line methods from vertical photographs. The density to which they are selected and marked will depend upon the detail to be compiled and the scale of the final map. As a rough guide, they should be selected so as to be spaced at about 2-inch intervals on the scale of the compilation. The points must appear on at least two obliques in order to establish their position by intersection. Many will appear on three or more. It should be sufficient to mark them on three obliques. These points should be inked with still another distinctive color and assigned numbers to facilitate later identification. Points of this type are not included in the original minor control plot and will be referred to hereafter as "compilation points" to differentiate them from the points mentioned in the preceding paragraphs.

c. Identification. (1) All points must be selected, marked, and transferred with the aid of stereoscopic viewing with both vertical and oblique exposures. Great care must be exercised in selecting and marking points on the obliques, for the appearance of features changes greatly from the first to the last exposure on which they appear. Stereoscopic viewing will aid greatly in evaluating the differences in viewpoint so that identical points may be marked. Stereoscopic viewing is difficult on obliques, but can be used to advantage. Where crab is great, stereoscopic viewing in the foreground of the obliques may prove impossible.

(2) It is extremely difficult to locate identical points from two obliques taken in directions opposing each other. Great care must be exercised in this case. Viewing pairs from each flight stereoscopically will aid in eliminating errors.

62. Intensifying Detail

The methods used to compile detail from both vertical and oblique photographs of the Tri-Metrogon assembly require that the detail to be plotted be intensified on the photographs. The devices used in plotting result in a lack of contrast in the photographs as viewed, and detail is indiscernible. Intensifying the detail is a convenient operation with which to select and coordinate the features to be plotted. These should be traced over with colored pencils or inks so as to obtain a dark and readily apparent line. A color legend should be established for the various features, and classification symbols set up. With proper coordination and execution of this operation, the map will pass smoothly through the subsequent operations with a minimum of checking and editing.

63. Radial-line Plot of Vertical Photographs

a. General. At some time following the selection of the minor control points on the vertical photographs, and prior to assembling the oblique templates for the minor control plot, it is necessary to make a radial-line plot of each strip of vertical photographs. First, this furnishes data for the approximate location of the oblique minor control points so that the slots may be placed properly; second, it furnishes the data for connecting the

plumb points of the oblique templates in the minor control plot.

b. Scale of Plot. The radial-line plot is not normally made to control, but is made independently to an approximate scale based on the flight height. Knowing the approximate flight height and the scale to which the minor control plot is to be made, the proper distance between principal points in the radial-line plot may be determined so as to obtain approximately the desired scale. As the scale of the map prepared by these methods will generally be less than half the scale of the vertical photographs, the radial plot and the minor control plot should be at half the scale of the vertical photographs. This reduces the size of the work where extensive areas are to be covered, and is the smallest scale to which the plotting may be done, since the range of the oblique sketchmaster is limited to this reduction. The scale of the radial-line plot should be at the scale of the vertical photographs when a map at this or slightly smaller scale is to be prepared. Use of Tri-Metrogen photography for mapping at scales larger than those of the vertical photographs is not practicable.

c. Methods. The radial-line plot of the verticals is executed to the desired approximate scale by the usual methods. It may be either a graphical method or a slotted template method employing either slotted cards or slotted arms. If slotted cars are used for the oblique templates in the minor control plot, it will be advantageous to use slotted cards for the radial plot of the verticals. If slotted arms are used for the oblique templates, a graphical method for the radial plot will probably be best. The slotted arms for the radial plot of the verticals will achieve the desired result but will probably take longer to use than the conventional graphical method. In any event, the radial plot should be made on a strip of tracing paper or acetate sheeting sufficiently long and the positions of the minor control points marked thereon and clearly identified.

64. Directions from Obliques

a. General. Following selection of minor control points on the oblique photographs and prior to assembling the minor control plot, it is necessary to determine from the obliques the horizontal directions to the points selected. These are horizontal directions from the plumb points of the exposures, as discussed in paragraph 55. Directions to the points of both obliques of a set are determined and shown on the same piece of tracing paper. Since both obliques have the same plumb point, the horizontal directions for both sides radiate from the same point. Further, since the computation of the camera settings, the horizontal angle between the direction of pointing of the two oblique camera axes has been determined: this fixes the relative position of the two groups of directions found from both sides of the set of obliques. Thus the directions to the points on each side of the vertical form a rigid assembly. This can be resected on the radial-line plot by use of the directions to those points of the radial plot that were selected to appear on the obliques.

b. Templates. Tracing paper for the horizontal directions from the obliques should be cut and prepared in advance. The paper may be of any type sufficiently transparent; but, where maximum accuracy is desired, it must be of a good grade having favorable shrinkage characteristics. It should be slightly longer than the spacing between flights at the scale of the minor control plot, and slightly wider than the width covered by the obliques at the scale of the minor control plot at a point midway between flights. On a piece of the tracing paper, or film base of the same size, there should be laid out the angle between the horizontal directions of the two oblique camera axes. This should be constructed with the angle point in the center of the piece of paper, and the lines forming the angle extending in the long direction of the paper and about centered in its width. The angle point represents the point *O* of figure 24, which point is the same for both left and right obliques, as they had the same exposure station. The left and right directions should be marked on the proper sides. This angle is used next as a template, and traced on all pieces of tracing paper cut. Both lines should be traced across the full length of the paper, and their intersection clearly marked. The left and right ends should be clearly marked on each paper, and the sheets may be numbered for each set of photographs for which they are to be used. An example of a sheet so prepared is shown in figure 30. The example also shows the additional construction lines needed for the graphical method.

c. Graphical Solution. (1) When the graphical method of determining horizontal directions from the obliques is used, some additional lines and distances must be placed on the template and

traced on the tracing-paper sheets. The position of the true horizon is located for each side of the set of obliques, and measured out from the angle point, O. Perpendicular lines for the horizons are drawn at the distance OH_R and OH_L, as shown in figure 30. The distances are determined as shown in figure 24. Between the angle point O and the horizons, the two principal points are located. Back on each line from the angle point O, the two plumb points are located. All are clearly identified, marked, and traced on the tracing-paper sheets.

d. Use of Angulator. (1) As explained in paragraph 55*b*(3), the angulator is used mechanically to solve the graphical extraction of horizontal directions from the oblique photographs. The result of its use is the same as that obtained from the graphical solution illustrated in figure 31. The photographs are prepared as described in *b* above.

(2) Referring to figures 25 and 26, it is seen that there are two settings to be made on the angulator prior to its use. The proper position for the principal point of the photograph must be determined, and the proper setting must be made on the connector arm. The former operation actually determines the distance NP, while the latter determines the distance $O'H'$.

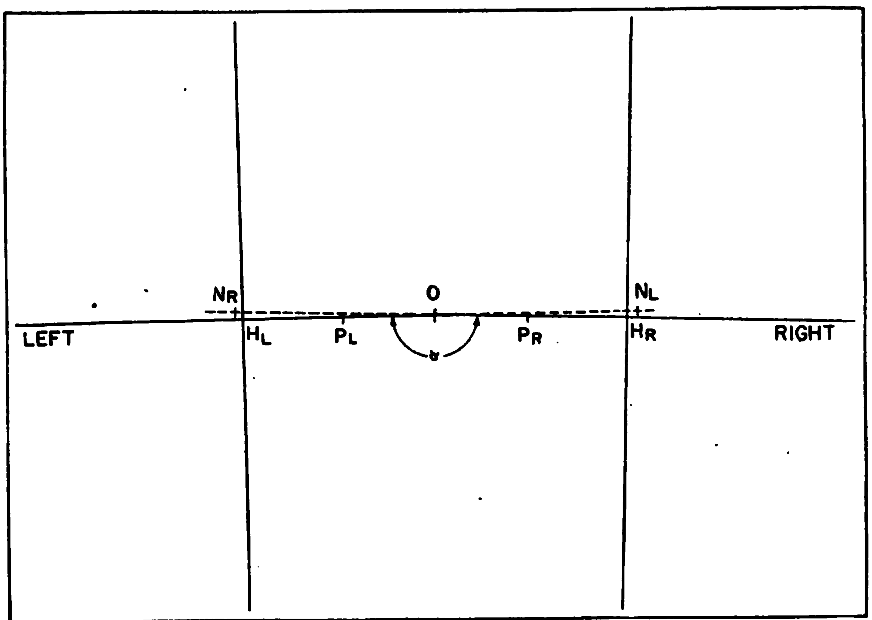


Figure 30. Specimen template for extraction of horizontal directions.

(2) To use the graphical method, an oblique photograph is placed under the proper side of the tracing paper, the principal point placed under the indicated mark, and the photograph rotated to bring the line normal to the horizon under the line OPH. The photograph and paper are secured in this position. Then, with a ruling edge pivoted at the corresponding plumb point, lines are drawn through desired image points to intersect the horizon line. (See fig. 31.) The ruling edge next is pivoted about O and the horizontal direction lines are drawn through the intersections on the horizon line, as illustrated in figures 23 and 24. The direction lines are marked for proper identification. The directions for the oblique of the opposite side are obtained in the same manner, using the other side of the template diagram.

(3) The photo scales provided on the angulator are for locating the position of the principal point, and are laid out as determined from the relationship $NP = f \cot \theta$. The tilt scales are computed with f constant at 6 inches, while the focal-length scales can be used directly for all combinations of tilt and focal length.

(4) For tilts within one or two degrees of 30°, or for focal lengths within approximately .04 inch of 6 inches, the scales are used in the following manner to locate the principal point. First, the division on the tilt scale is noted for the actual tilt of the photograph. Next, the distance is noted on

the focal-length scales between the 6-inch graduation, and the actual focal length of the camera. If the actual focal length is greater than 6 inches, the distance noted is added above the tilt division noted and determines the distance from the pivot for the principal point. When the actual focal length is less than 6 inches the distance noted is added below the tilt division noted at first. When tilts and focal lengths are further removed from 30° and 6 inches, then the distance *NP* must be

parallel to the horizon coinciding with the line set on the proper scale divisions. The photograph is then fastened to the board in that position. The connector-arm scale is then adjusted for the actual tilt of the photograph.

(6) The tracing-paper templates are placed on the plotting board under the ruling arm, which is easily removed for that purpose. The paper is placed so that the pivot point O' pierces the paper at the angle point laid out on the paper. With

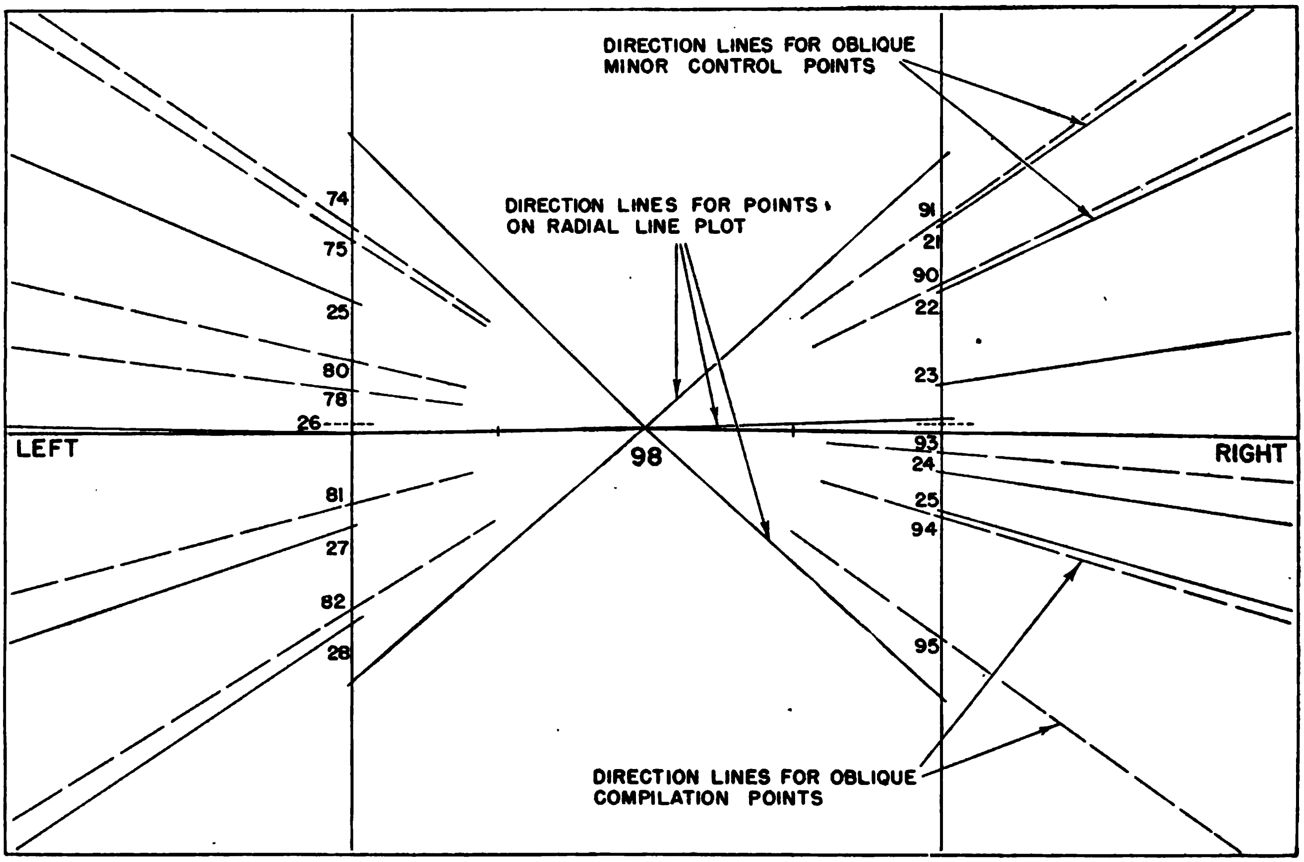


Figure 31. Specimen horizontal-direction template.

computed and substituted in the relation for *NP*, using a focal length of 6 inches and thus finding the correct setting on the tilt scales.

(5) When the proper position of the principal point is found, it is easily indicated by a line ruled on clear film base. The line is made to pass over the proper scale divisions and the film base is fastened to the plotting board with tape. Then, with the aligning marks coinciding, the photograph is slipped under the photo arm and placed with its principal point on the center line of the arm, with the line through the principal point and

the rule back in position, and the aligning marks coinciding, the template is then rotated so that the line representing the horizontal direction of the optical axis lies along the ruling edge. The sheet is fastened in this positon. The line on the photo arm is then placed successively over the various points on the photograph, and horizontal direction lines of the proper length are ruled along the ruling edge and marked with proper identification. The horizontal directions for the opposite oblique are ruled in the same manner, with the proper photograph in position for its tilt and

focal length and with the tracing paper rotated through about 180° and aligned for the opposite side in the manner described above.

65. Locating Slot Positions

a. General. Horizontal direction sheets obtained as in the preceding paragraphs are the basis of the minor control plot. Since the lines on a given sheet represent horizontal directions from the plumb points of the exposures to the various points marked, it is possible by resection to locate the position and orientation of the sheet if the positions of at least three of the points are known. If two overlapping sheets can be thus oriented, the position of additional points may be determined by intersection. Since sufficient known positions are never available to proceed in this manner it is necessary to connect all the sheets in a form of radial-line plot to reach between available known control positions. The sheets as prepared contain all data necessary to do this by the slotted-template method except that there is no indication of where slots should be placed along the direction lines and there is no "azimuth" connection between successive plumb points. The radial-line plot of the vertical photographs made at the approximate scale of the minor control plot furnishes these two missing items.

b. Resection on radial-line plot. The sheets containing direction lines are next resected on the radial-line plot as illustrated in figure 32. As the six points at the sides of each vertical exposure were selected to appear in the obliques, there will be six lines on each sheet to adjust to pass through six points on the radial-line plot. Where there is a large amount of crab, only four points may appear on the obliques, but this is one more than is needed to establish the resection. With the sheets resected, it will be found that the point O representing the plumb-point position probably will not coincide with the principal point of the vertical photograph as located in the radial-line plot. This is because small tilts in the vertical photographs cause the plumb point to be displaced from the principal point.

c. Marking Slot Locations. Several horizontal direction sheets are resected on the radial-line plot at one time, this being done best on a light

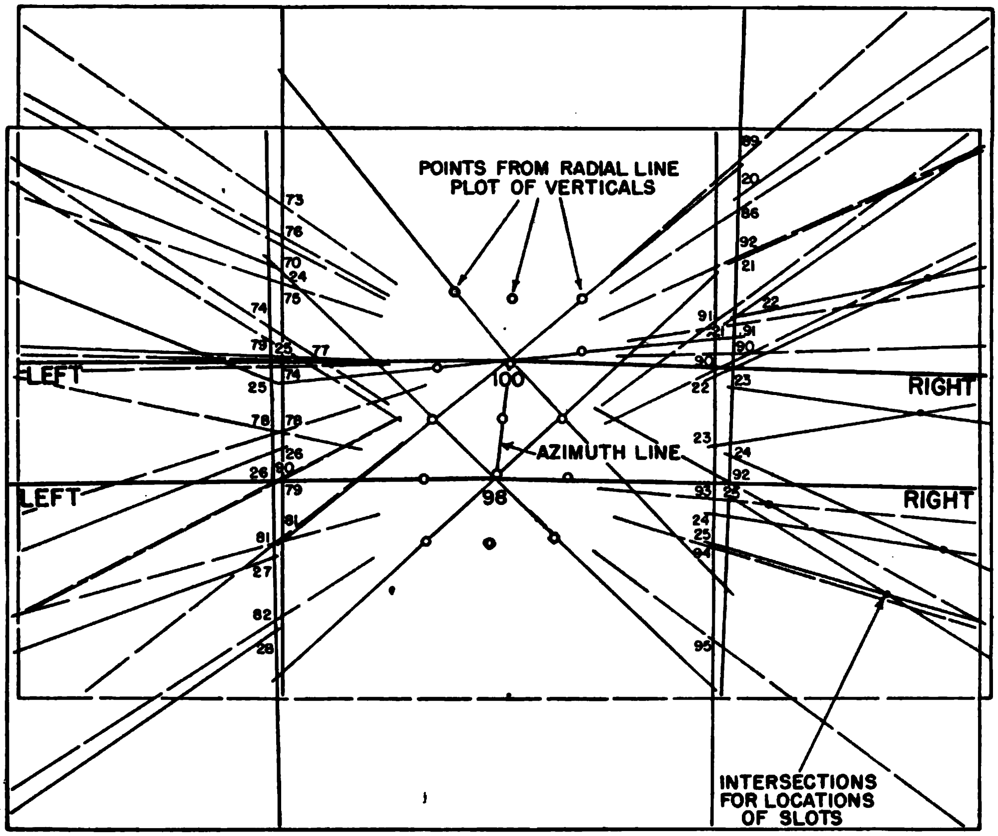


Figure 32. Horizontal direction sheets resected on radial-line plot.

table. It is then seen that the intersection of the corresponding direction lines establishes the position of the oblique points with reference to the radial-line plot, and hence at the approximate desired scale. (See fig. 32.) The position of the intersection is marked on the lines of each sheet and hence shows where the slots should be centered. The intersections are marked for only the minor control oblique points, as these are the only ones set up in the plot. Also, with successive sheets resected on the radial plot, lines are drawn on each sheet showing the azimuth lines to the oblique plumb points preceding and following. These lines need not be drawn if the slotted cards are used for the minor control plot.

d. Alternate Templates. It is necessary to resect only the horizontal direction sheets for the alternate sets of exposure, since slotted templates need be prepared only for these in the minor control plot. Though using the Tri-Metrogon photographs for the maximum accuracy requires the use of direction sheets for all exposures, it is necessary to use only alternate sets for the minor control plot.

66. Slotted Templates

a. General. After the horizontal direction sheets are marked as above to show the approximate positions of the minor control oblique points, slotted templates may be prepared for the minor control plot. These may be prepared with the conventional cardboard material and a slot cutter, by the use of mechanical, slotted template equipment (slotted arms).

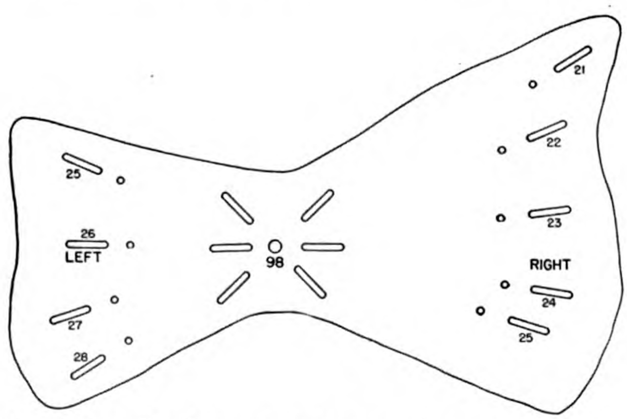


Figure 33. Specimen of oblique template prepared with slot-cutter.

b. Slotted Cards. Cardboard material should be prepared in advance and cut to correspond to the size computed for the tracing-paper direction sheets. Tracing-paper sheets, prepared and marked to show the location of the slots, are placed over and fastened to the cardboard. The position of the plumb point is then pricked through onto the cardboard. Likewise, a prick mark is made through each of the direction lines for the minor control points at the position along the line marked in the previous operation. The cardboard is then removed, the prick marks circled for easy location, the number of the exposure and the direction of flight—or right and left sides—marked, and the numbers of the minor control points placed by the respective prick marks. The plumb point is then punched out with the center punch of the slot-cutting equipment. The slots then are cut so as to radiate from the plumb point. Some diffi-

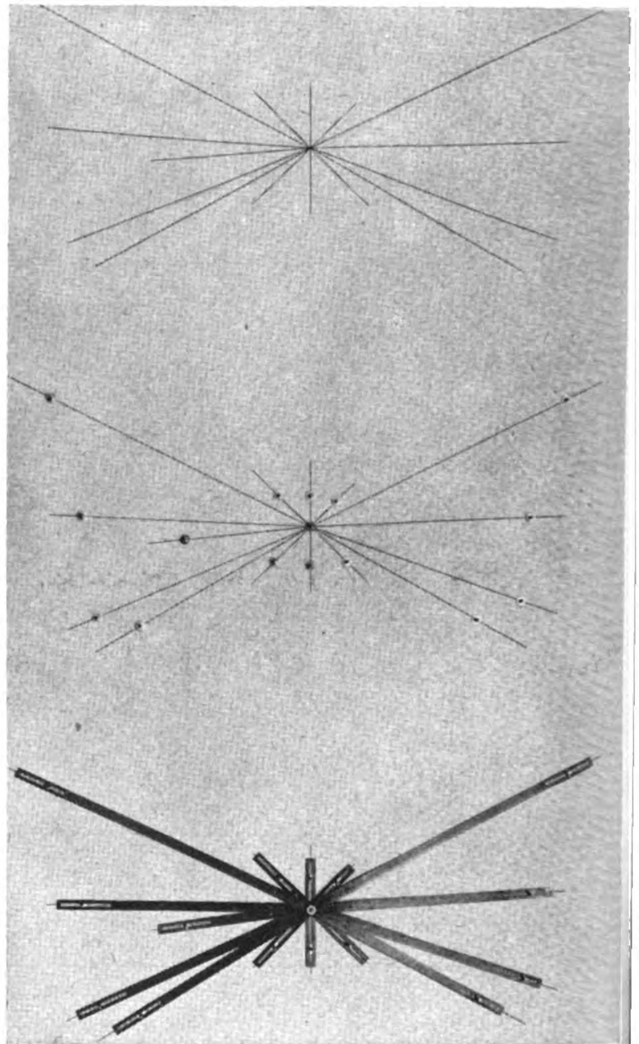


Figure 34. Steps in assembly of slotted-arm template.

culty may be encountered in using for this purpose the small slot-cutter designed around a 9- by 9-inch vertical photograph. By pricking additional positions for pivot points along the direction lines out near the distant slots, the slotting can be done satisfactorily. Following the slotting, the excess cardboard should be trimmed off so that the template takes about the shape of a rectified oblique. The plumb point pivot hole should also be punched out to about twice its original diameter. A template of this type is illustrated in figure 33.

c. MECHANICAL, SLOTTED TEMPLATE. (1) If the mechanical, slotted template (slotted arm) equipment is used, the horizontal direction sheet is fastened on a soft wood drawing board or table. A threaded stud is pinned over the plumb point and smooth studs are pinned on the horizontal direction lines at the points indicated from the previous operation. A smooth stud is also pinned on each azimuth line about half way out to the position of the next plumb point. Slotted arms are then selected so that, with the holes at one end placed over the threaded stud, the smooth studs will be about centered in the slots. A hexagonal washer is placed on the threaded stud on top of all the arms, followed by a round washer and a hexagonal nut. With the double hexagonal wrench placed to hold both the hexagonal washer and stud, the nut is tightened with a socket wrench. The double wrench prevents any resultant twist from being transmitted to the arms. Figure 34 shows the steps in the assembly of a slotted-arm template.

(2) Following completion of the mechanical, slotted template, it is removed as a unit from the pins and its identifying number placed on a piece of Scotch tape attached to the template. Numbers are also advisable on the individual arms, for easy reference in later assembly of the minor control plot.

d. PLOT WITHOUT TEMPLATES. If control density is great enough to fix the radial-line plot of the vertical photographs to scale and position, it is not necessary to use slotted templates for obliques. Horizontal direction sheets may then be resected on the radial plot so fixed, and the intersection for all oblique points marked directly. This condition is desirable, but probably rare.

67. Minor Control Plot

a. PROJECTION. A projection for the area to be mapped should be prepared in advance on suitable material large enough to cover the area to be set up at one time in the minor control plot. Any type of projection may be used provided it introduces only negligible distortion for the area. Normally, the polyconic projection will be found most convenient. The available control should then be plotted on the projection, the entire projection convered with tracing paper or acetate sheeting, and the projection and control traced onto this material. Where the area is large, and more than one strip of material is required to cover it, the strips should be wide enough, and so placed, that the compilation of any one strip of photographs need not be placed on two sheets. A sufficient overlap should be provided between such strips of paper, and the projection fully traced on each, so that they may be properly registered again after any movement.

b. TEMPLATE ASSEMBLY. Oblique templates are assembled in much the same manner as vertical templates in a radial-line plot. In using slotted cardboard templates the vertical templates are assembled first, the oblique templates are then placed on top with the six slots passing over the proper six studs at the edges of the verticals and connected in the obliques with additional studs. The whole assembly is held by studs pinned at the control points. Mechanical, slotted templates are assembled in much the same manner, but do not require vertical templates. They require two studs placed in the azimuth arms between the templates so as to provide a sliding connection. In using slotted arms, the radial-line points at the edges of the vertical exposures opposite the principal points corresponding to the templates are not represented in the assembly.

c. MARKING POINTS. After templates are assembled and interconnected between controls, pins are inserted through the holes in the studs and tapped, to prick through the paper or acetate sheeting covering the projection lay-out. The templates are disassembled, and the prick marks circled and given their identifying numbers. Exposure numbers are written by the centers of templates to identify their locations properly.

d. COMPILATION POINTS. The strips containing minor control point positions may now be taken up from the projection lay-out and handled separately to obtain the position of compilation points. On a light table, the oblique horizontal direction sheets are resected again on the minor control point positions on the strips, and the positions of the

compilation points are marked from the intersections appearing for them. This completes the sheets up to the stage of the detail compilation.

68. Compilation

a. VERTICALS. (1) *Method.* The vertical photographs are best compiled first. Detail is compiled on the sheets of tracing paper or acetate sheeting on which the minor control and compilation points are located. Normally, the points on the vertical photograph which are located from the minor control plot are sufficient to control the compilation of the detail. Where maximum accuracy is demanded in the map, additional compilation points then may be "cut in" by conventional radial-line methods. Planimetric detail is compiled as described in paragraph 48 for compilation in connection with the radial-line plot.

(2) *Vertical sketchmaster.* The vertical sketchmaster was designed especially for use in plotting planimetric detail from the vertical photographs of the Tri-Metrogon assembly. It is pictured in figure 35. Using this device, the photograph is viewed by means of a semitransparent mirror so as to superimpose the photograph on the paper for guiding the sketching. The plane of the photograph is set approximately parallel to that of the paper. Provision is made for tilting the photograph with respect to the plane of the drawing paper, to compensate for small tilts, and also for varying the height of the device so that scale changes may be effected. The device permits plotting at scales between that of the photographs and one-half that scale.

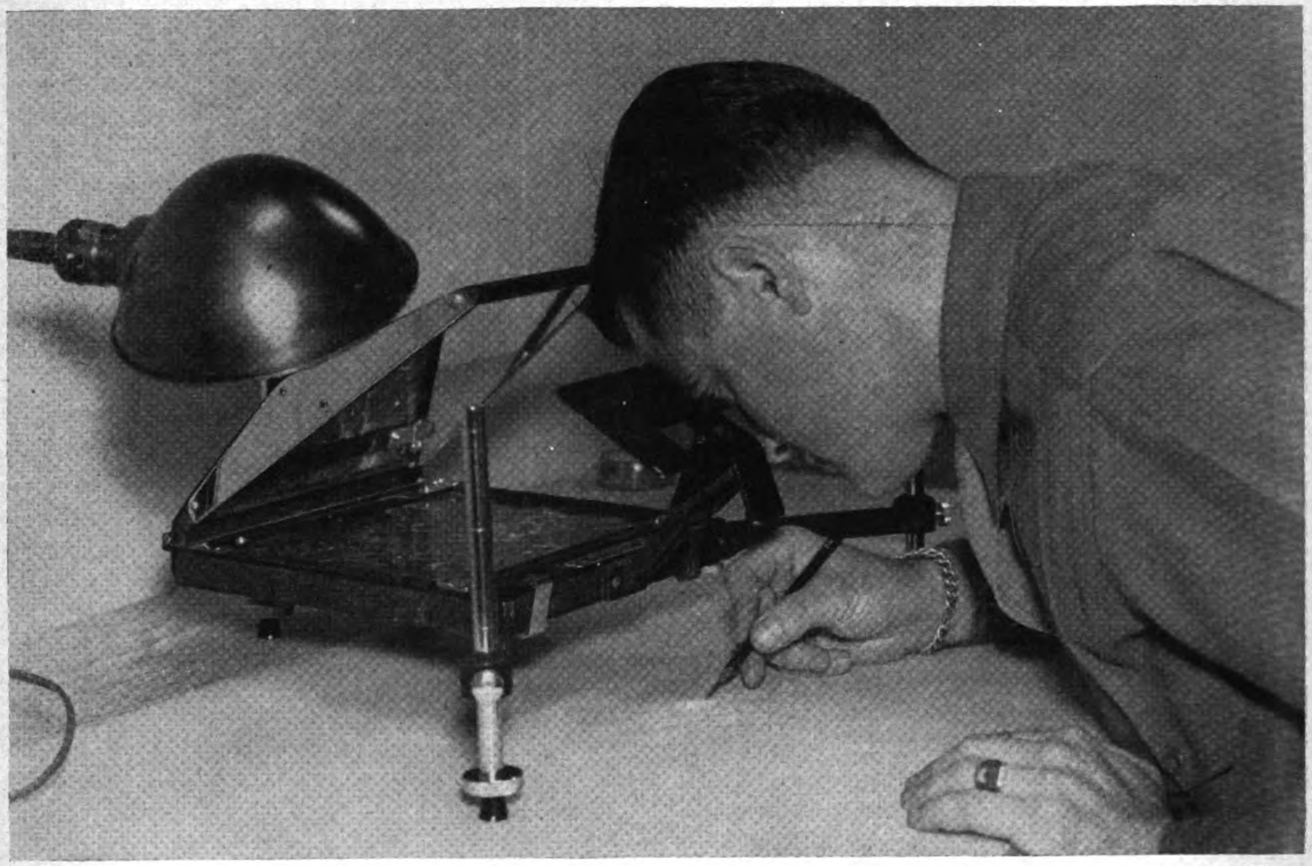


Figure 35. Vertical sketchmaster in operation.

b. OBLIQUES. (1) *Oblique sketchmaster.* The oblique photographs are compiled following the verticals on the same sheet with the aid of the oblique sketchmaster, illustrated in figure 36. The photograph and the two mirrors are held rigidly as a unit in the device. An opening in the framework permits viewing with the eye in the position of O, as shown in figure 37. The unit may be raised or lowered as a whole to vary its distance from a horizontal plane on which the device rests during compilation. This provides for changing the scale of the rectification. Also, the

unit may be tilted as a whole to change the tilt of the photograph with respect to the plane on which the device rests. This permits compensation for small variations in tilt from 30°. The device may also be tilted in a direction normal to the plane of the paper (fig. 36) by adjusting the supporting screws to permit compensation for small errors in that direction. Although the device is designed for the purpose of compiling at one-half the scale of the equivalent vertical photograph, it may be used for large scales by using a block to raise the front supporting leg.

(*a*) Although the principle of the oblique sketchmaster is theoretically sound for the conditions around which it is designed, the device is essentially an aid to sketching. It is impractical to place and hold the eye while viewing exactly at the point *O*, and hence the correct perspective is not covered. Likewise, for tilts varying from 30° and focal lengths from 6 inches, true conditions are not obtained. However, the device does present a reasonable rectification and, when controlled and adjusted by a minor control plot, enables the detail to be compiled in its reasonably correct shape and position.

(*b*) The oblique sketchmaster designed and built for work with Tri-Metrogon photography cannot be used with other oblique photography where focal lengths and tilts are materially different from those of the Tri-Metrogon oblique.

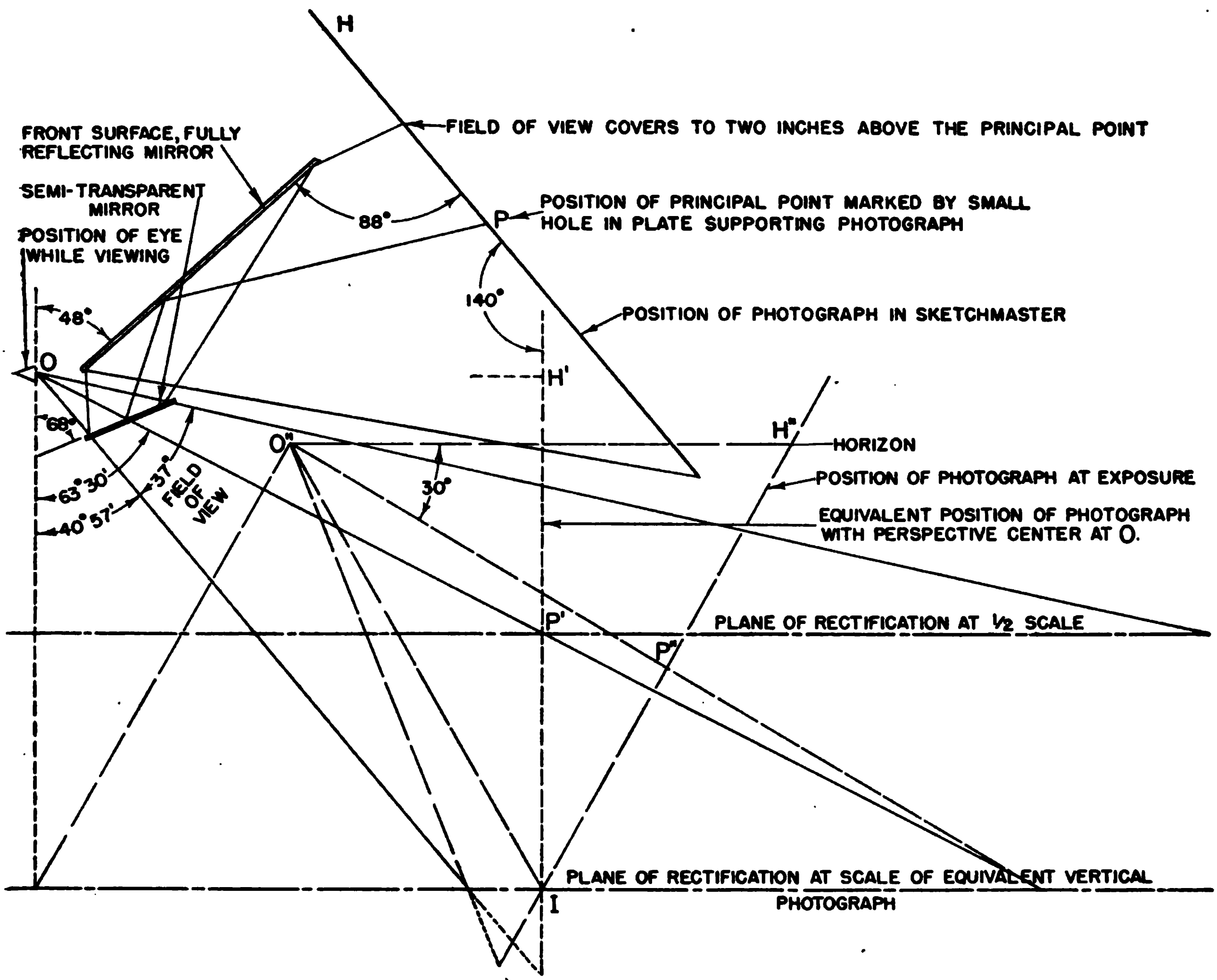


Figure 36. Principle of oblique sketchmaster.

(2) *Method.* The oblique photograph is placed in the device with the principal point over the small hole in the plate back of the photograph. The photograph is rotated so that its horizon is parallel to the edge of the opening in the holding frame. Then, with the oblique sketchmaster set over the

compilation sheet with the viewing aperture approximately over the position of the plumb point for the exposure in use, and the device pointing out away from the center of the strip, the photograph may be viewed so as to appear superimposed on the sheet of paper in its approximately rectified form. By adjusting the tilt and height of the oblique sketchmaster, and by shifting its position as needed, the compilation points marked on the photograph are made to appear superimposed on their positions as determined on the compilation sheet. This adjustment is performed for successive groups of points including a small section of the photograph and, when coincidence is obtained, the intervening, intensified detail is traced off on the sheet where it appears. Continual adjustment of the oblique sketchmaster will be found necessary.

(3) *Aids to compilation.* The lighting on the compilation sheet and on the photograph is quite critical, and a source of constant annoyance. One satisfactory solution uses a light table for the work. With the transparent compilation sheet on the glass surface, the light illuminates the sheet and passes on to illuminate the photograph. Control of the amount of light permits needed adjustments. To reduce fatigue, the table top is placed at about chin level for the operator when seated. Since the oblique sketchmaster must be placed near the front edge of the table to permit viewing, and since the center of the strip of photographs on the sheet must be under the viewing point, it may be desirable to cut the compilation into smaller sections for this operation. This may be done by making a clean cut down through the center of the flight than has been

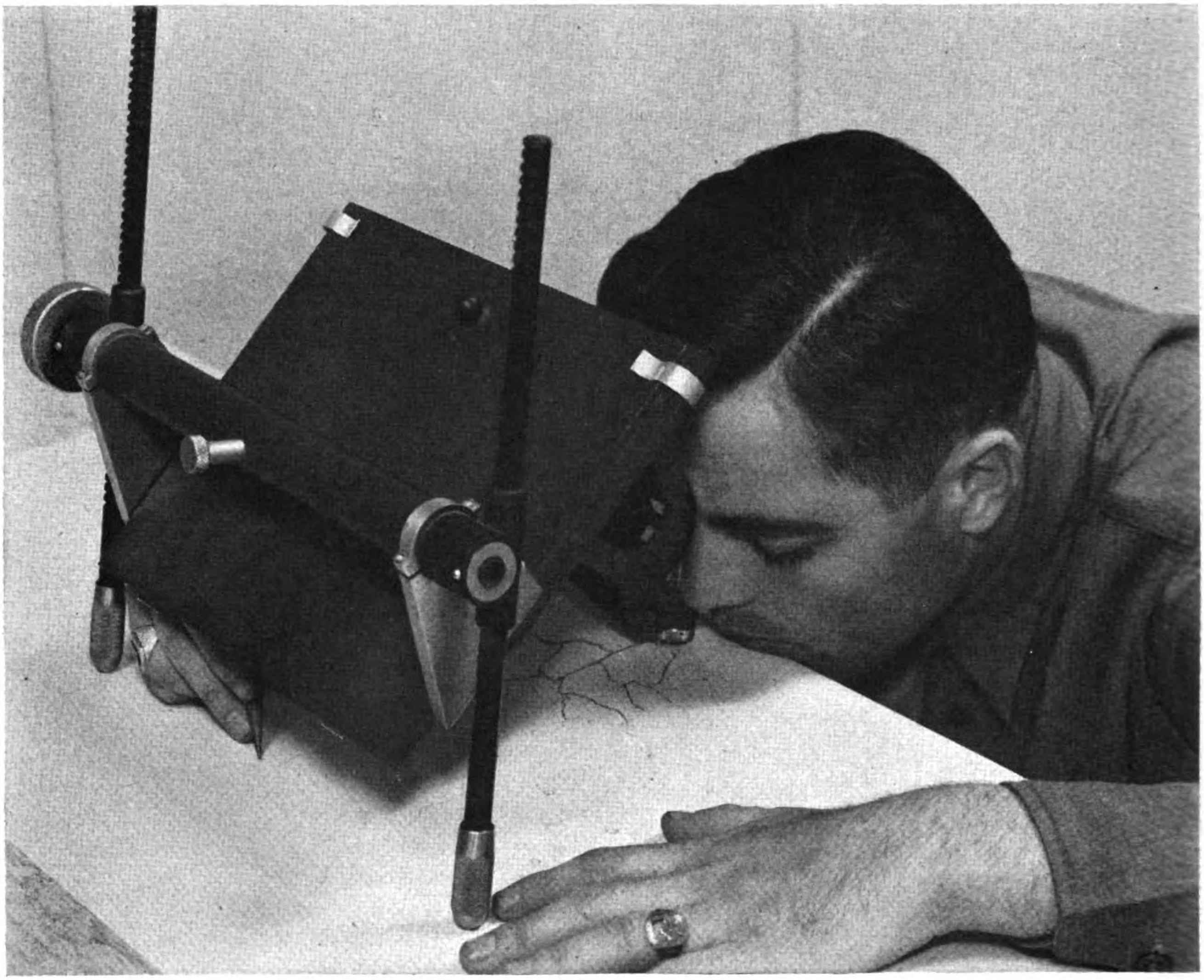


Figure 37. Oblique sketchmaster in operation.

compiled from the verticals. The pieces then may be rejoined as required.

c. DRAFTING. After the compilation of the entire area or its subdivisions has been completed, the map may be put through the remaining operations necessary to obtain the type drafting and reproduction desired. One convenient system is to join and match as many pieces of the compilation sheet as are required for a reproduction unit, and to copy this unit photographically to a scale slightly larger than the final scale desired. From the negative, the desired number of blue-line prints may be made for color-separation drafting. The final ink drafting and lettering may be done on these blue-line prints and the plates for printed reproductions prepared from them. The actual system used must be adjusted to the map desired and the equipment and personnel available.

69. Accuracy

a. POSITION. To achieve an accuracy of position comparable to that obtained with vertical photography and the radial-line plot, a procedure must be used which will give the greatest precision. This includes determining tilts for each exposure, changing template or angulator settings for each exposure in plotting the horizontal direction sheets, and the use of more compilation points in compiling detail by means of the sketchmaster. Such a system is feasible, and should result in a map containing position errors only slightly greater than on one prepared from vertical photography and the radial-line plot with the same control.

b. REPRESENTATION. (1) For the type of map normally compiled from Tri-Metrogon photography great accuracy of position is not required. Accuracy of detail is more important than accuracy of position. However, as the scale on the oblique photographs diminishes rapidly in a direction away from the plumb point, and as the angle of view becomes flatter, some point is reached beyond which it is not possible to identify features to be plotted. It is difficult to say just where the dividing lines occur. It can be said, however, that the limit for natural features is farther out than the limit for man-made features. For this reason, this type of photography is more suitable in terrain where natural features are the prime ones to be plotted. Where man-made features are involved, the limit of the usability of the obliques is near the principal point, or at an angle of 60° from the plumb line of exposure. Oblique photographs should not be relied upon beyond that point to provide information for tactical maps for use of ground forces.

(2) Tri-Metrogon photography has been used extensively in preparing aeronautical charts of remote and undeveloped country, with flights spaced at 25 miles. Under such conditions, the actual distance between flights is often 30 miles or more. This requires using the obliques to a distance of 15 miles. With a flight altitude of 20,000 feet this requires that the oblique print be used to a distance of about 1.75 inches beyond the principal point, where the scale is approximately 1:160,000. The angle from the plumb line to features occurring at this distance is approximately 76°. It has been found that satisfactory charts can be prepared for such terrain with this flight spacing. This is stretching the system to the utmost, however, and probably 20-mile spacing for such uses would be more advisable. It should, of course, be varied to suit the altitude at which the photography is done.

SECTION VIII

PHOTOMAPS

70. General

a. A photomap is a reproduction of a single photograph or an assembly of two or more photographs upon which grid lines, marginal data, and place names have been added. Often situations arise where map information is desired but there is not sufficient time to prepare maps of optimum quality. In such situations, the photomap made from a single aerial photograph or from an uncontrolled mosaic is valuable since it may be produced rapidly, has a wealth of pictorial detail no map can equal, possesses accuracy of form, may be produced in quantity by lithography, and may be made of an area otherwise inaccessible because of either physical or military reasons. Such a photomap, however, is inferior to a map, since it shows positions and directions inaccurately, relative relief is not apparent, and important military features which are emphasized on a map may be obscured or hidden by other detail.

b. Where sufficient time is available photomaps may be made from controlled mosaics, on which the accuracy of position and direction approaches that of a map made to the same ground control. However, since about as much time is required to make such a mosaic as to make a complete topographic map, it is of little value except in special cases. This section contains instructions for making all types of mosaics by the most advanced methods.

71. Photomaps from Single Photograph

The simplest and most rapidly produced photomap is made from a single photograph. Normally it is made from a single vertical photograph, although an oblique photograph may be used. Vertical photographs taken by the K–17 camera with a 6-inch cone, or the T–5 camera, at altitudes of 20,000 feet or higher, are satisfactory for photomaps. At 20,000 feet the area covered by these cameras is about 36 square miles, giving a photograph scale of 1:40,000. A two-time enlargement of such photography produces a photomap 18 inches square at a scale of 1:20,000. Photomaps are normally reproduced at scales of 1:20,000 or 1:25,000. A reproduction of a photomap is shown in figure 38.

72. Preparations for Mosaicking

a. GENERAL. Assembling two or more photographs to form a mosaic can be done in several ways, depending upon the amount of time available and control available, and the type of photography. The result is an uncontrolled, semicontrolled, or controlled mosaic in some form. The basic methods employed in preparing photographs and materials for mosaicking of any type are discussed in the following paragraphs.

b. PHOTOGRAPHS NECESSARY. Normally, two contact prints of each negative on single-weight, glossy paper are required for mosaic work, in addition to the set of quick prints obtained for the photographic index. For best results, the density and tonal range for all prints must be uniform. Contrast should be slightly less than normal so that fine detail in the shadows and in the high lights is not lost in the reproduction. Prints for mosaic work should not be ferrotyped, but dried naturally. Forced drying or ferrotyping may cause distortion in the prints in addition to that already caused by tilt and relief, thus making assembly more difficult.

c. FEATHEREDGING THE PRINTS. Featheredging is a process in preparing the photographs for mosaicking and involves cutting, tearing, and sandpapering the back of the print along its edges in such a way that the edge of the print is thin and will make a smooth match with adjoining prints. It may be done in several ways. Where it is desired to make the match along straight or smooth lines, cut gently straight through the emulsion along the desired line with an ordinary stiff-back razor blade; or with a sharp knife cut through the print along the desired match line at a flat angle. Fold the print back lightly along this line. Then hold the print between thumbs and forefingers of both hands so that the emulsion is toward the assembler, and twist the left hand in and the right hand out so that the emulsion side of the print which is to

be retained is given a sharp, beveled edge. Where the match is to be through a wooded area or some other place where a jagged match line is desired, an irregular cut is made and the print is torn along that line; or, the tear may be made without the aid of the cut. After the cut or tear is made, the edges are sandpapered to remove any roughness. For this it is desirable to have a wood block about 2 inches thick and about 10 by 10 inches in area, with one edge rounded into about a 2-inch radius. The print to be sandpapered is laid face down with its edge extending over the round portion of the block. The sandpaper is mounted around a roll of paper or cardboard about 2 inches in diameter. The sandpaper is drawn over the edge of the print away from its center, and not along the edge.

d. Mount. Many types of material are suitable for mounting mosaics. The prime requirement is that the surface must not have such a high gloss that the prints will not adhere firmly

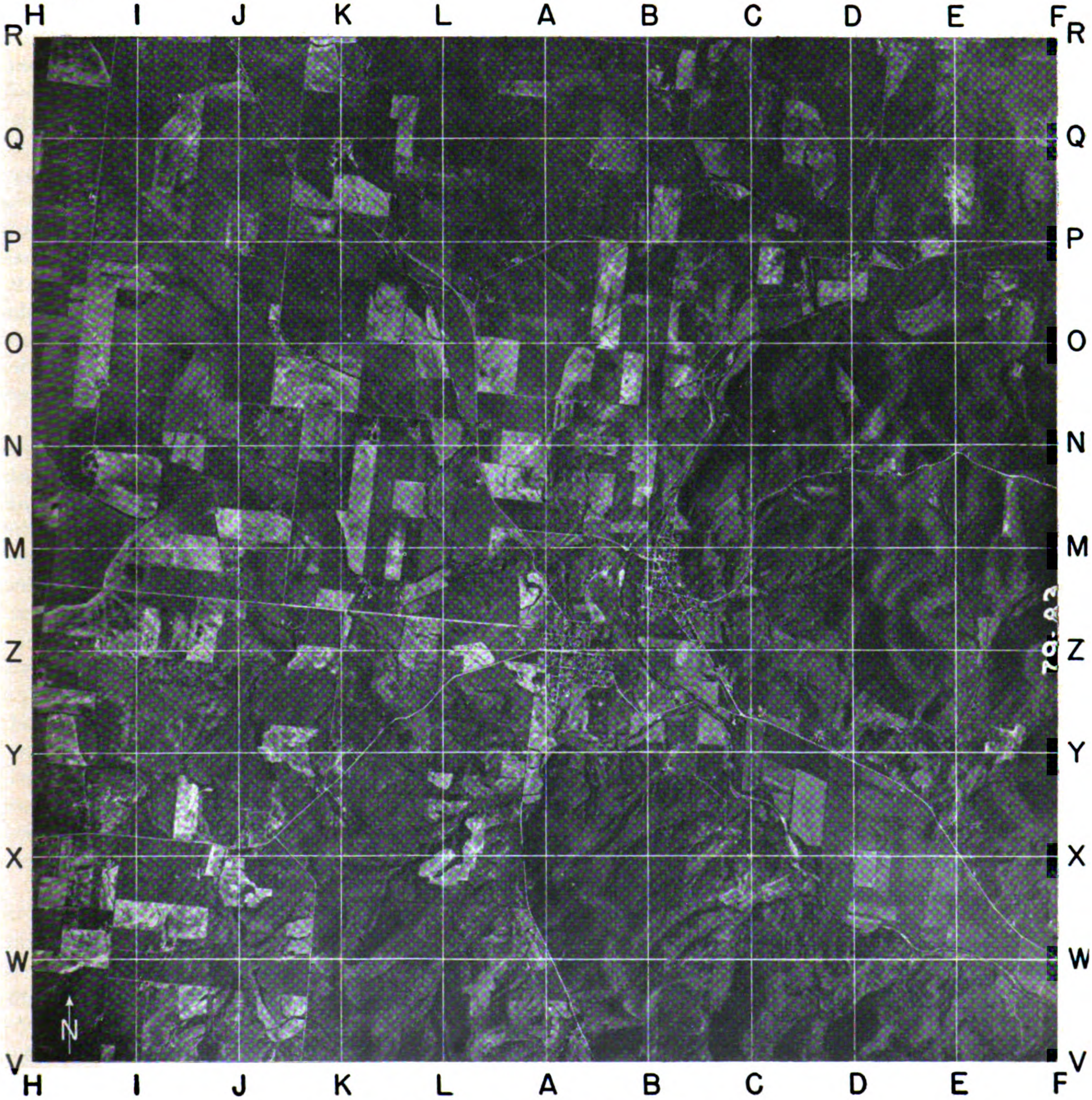


Figure 38. Photomap with point-designation grid.

to it. Probably the most satisfactory mount is the composition board known commercially as Vehisote. Other suitable materials of the rigid type are plywood boards and Masonite. Uncontrolled mosaics may be mounted satisfactorily on cloth or on a good grade of detail paper stretched over a board or drafting table. Mosaics on flexible material of this kind may be rolled up for easy transport. Other materials suitable for small mosaics are ordinary wall board, strawboard, or bristol board. After the mosaic has been copied the prints may usually be removed from a rigid type mount and the board used again for other assemblies.

e. ADHESIVES. Three types of adhesive are in common use for mounting mosaics—gum arabic, photo paste, and rubber cement.

(1) Gum arabic is the most widely used. It has slow setting properties and strong adhesive power. It is made by dissolving gum arabic (gum acacia) in water and adding salicylic acid and glycerin according to the following formula:

Glycerin	4 *ounces*
Salicylic acid	19 *grams*
Gum arabic	64 *ounces*
Water	120 *ounces*

More water may be added to dilute the solution. The addition of glycerin and salicylic acid is not absolutely essential, the glycerin being added to retard the setting of the adhesive and the salicylic acid to keep the solution from becoming sour in a few days.

(2) A paste known commercially as Sphinx paste, or Arabol, is highly satisfactory for mosaic work. When no other adhesives are available, a paste similar to this may be made from ordinary starch and hot water. Starch paste must be used within a few days after mixing, as it sours in a short time.

(3) Rubber cement, composed of unvulcanized rubber dissolved in benzene, is satisfactory for some types of mosaic work, but it is messy to use and is not permanent.

f. USE OF ADHESIVES. (1) (*a*) Gum arabic and paste are used in much the same manner. After the print has been trimmed or featheredged and is ready for mounting, it is placed in a tray of clean water and allowed to soak until limp. Then it is turned face down on a piece of clean tissue paper, or on the mount, and a thin coat of the adhesive is applied to it and to the area of the mounting board on which the print is to be placed. The print is then placed in position and smoothed out carefully with a bone or the back of a stiff-back razor blade, working from the center to the edge of the print to expel all air pockets and excess adhesive. After the print is properly smoothed out the excess adhesive is wiped off with a damp sponge. Gum arabic or paste should not be allowed to dry either on the surface of the prints or on the board. When cloth or paper is used for the mount, it is best to apply the adhesive only to the print.

(*b*) Care is taken before final pasting to assure that terrain features are correctly represented. For instance roads, fence lines, or railroads which are apparently straight should be maintained as straight as possible from one print to another. When a satisfactory approximate over-all laydown is attained, the location of a number of the prints is marked by ticks at their edges and on the board, so their positions may be recovered as closely as possible when the prints are pasted to the mount. All except the center print or the print chosen as the desired starting point are then taken from the board and piled at each end in the order in which they are to be mounted. The edges of the first print are feathered and the print is mounted as described in paragraph 72*f*. An adjacent print is taken and the proper line of match with the affixed print is determined, after taking into consideration the tone match as well as the detail match. The line of match may be marked lightly on the face of the print with a red or yellow grease pencil, the marks being removed with a clean cloth after the print is feathered and prior to applying the adhesive. Only the center portion of each print should be used, in order to reduce to a minimum the distortion errors due to tilt and relief. The print is then affixed to the board in its proper position overlapping the print previously affixed, and the mosaic thus expanded. Small mismatches must be allowed to remain as the work progresses, as otherwise excessively large mismatches may occur in other sections of the assembly.

(2) Rubber cement is quite satisfactory in mounting either single-weight or double-weight photographs. It is good for laying controlled mosaics, since it causes no stretch in the prints when applied. Mosaics laid with rubber cement are usually joined by butting adjacent prints together along the match line, rather than by overlapping and featheredging as with the other ad-

hesives. A thin coat of the cement is applied with either a brush or the hand to the back of the print and to the area it is to occupy on the mount; or, a small amount may be poured on the surface to be coated and spread thinly with the edge of a triangle or straightedge. It is then allowed to dry thoroughly. This takes at least 3 minutes. It may be left for several days without losing its adhesive qualities. When dry, the print is placed in position and rolled down with a print roller. When two surfaces coated with rubber cement are placed in contact they adhere immediately, and the print cannot be shifted or removed without the aid of a solvent. It is therefore important that the print be placed in its exact desired position at the first attempt. Where large sections are to be mounted with this adhesive, it is advisable first to cover with a sheet of acetate the area of the board coated with the cement except for a very small portion at the edge or at the line of match with an adjacent print. The print is then placed on top of the acetate sheet, where it may be shifted to the desired position. Then it is pressed in contact along the match edge, and the acetate sheet pulled from between the mount and the print while pressing the print in contact with the board as the sheet is removed from beneath it.

g. Joining Sections. In a large project, a mosaic must be laid on several boards. Two methods of maintaining the match between the boards are in common use. One is to place the boards side by side and lay the mosaic over the joint, after which the prints are cut along the joint with a razor blade or a sharp knife. Another method is to place paper tape on the board along the line which is to be common to both sections, and to lay the mosaic over this paper. The mosaic may then be cut along the match line through the paper strip, and the excess transferred as a strip to another board. The mosaic is then expanded on the second board from this strip. These methods speed up production by splitting the job into small units for several workers.

73. Uncontrolled Mosaics

a. General. An uncontrolled mosaic is an assembly of two or more photographs oriented by matching detail along lines common to adjacent photographs, without the aid of ground control. Such a mosaic gives a good pictorial effect of the ground, but may contain serious errors of scale and azimuth.

b. Assembly. (1) With perfect photography and terrain of low relief it might be possible to start with a print near the center of the mosaic area and build onto it in successive circles by matching detail. However, an attempt to lay a mosaic of an extended area in this manner will generally result in a large obvious mismatch in detail being thrown into one part of the mosaic; or in excessively large and obvious errors in scale and azimuth. Therefore, it is advisable first to lay a set of dry prints over the board, using tape, paper clips, or staples as for an index mosaic, and to adjust the various portions until an apparently correct lay-down is obtained.

(2) A butt-joint assembly of an uncontrolled mosaic may be made more rapidly. However, the resulting mosaic probably will have many mismatches in detail and in tone qualities. After the prints are laid dry, in index mosaic form, a cut is made in the overlap area through the prints. The center portion of each print is retained and mounted permanently on the base in jigsaw puzzle form. Rubber cement must be used for this type of assembly, to prevent stretch in the prints.

74. Strip Mosaic

a. General. A strip mosaic is essentially a special type of uncontrolled mosaic. In its simplest form it is a strip of vertical photograph spread on a flat surface in such a way as to give a good idea of direction and distance along the strip. Each photograph is laid over the preceding one in shingle fashion, so that the detail of the overlapping portions coincide. The photographs may be bound together with staples, paper clips, or tape.

b. Assembly. A method of assembly which improves the azimuth accuracy of the strip mosaic is as follows: First, the principal points of all the photographs are marked and transferred to the adjacent prints. If the exact center cannot be identified on adjacent photographs, then some image point near the principal point may be used as a substitute center. The first print is then fastened to the board or table, using tape or staples, and the second print is oriented over the first so that the line from its center to the transferred center of the first photo exactly coincides with the line on the first photograph between its center and the transferred center of the second photograph. Detail is

matched as nearly as possible, and the print is fastened in place. This procedure is repeated with each print until the assembly is completed. Each overlap is then cut through with a razor blade or a sharp knife, and the edges of the photographs are discarded. This cut may be made straight through the center of the overlapped area or, where such a cut would result in the elimination or duplication of important detail, it may be made along a diagonal or even-curved line, according to conditions.

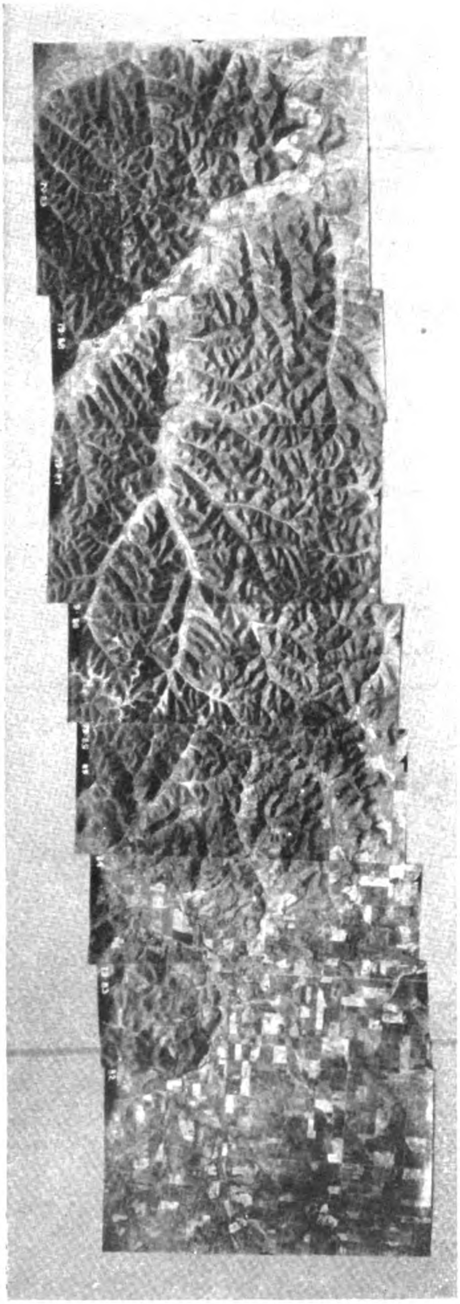


Figure 39. Strip mosaics.

After the cut is made, the remaining center portions of each print are taken up one at a time and fastened permanently to the board with an adhesive. A strip mosaic is illustrated in figure 39.

75. Index Mosaic

An index mosaic, or photographic index (fig. 5), is another form of uncontrolled mosaic and is essentially an assembly of several strip mosaics. Each strip is laid in shingle fashion as described in paragraph 47*a* for a shingled strip mosaic, and the adjacent strips are oriented by matching detail. This type mosaic may be made rapidly and, while it has no position and azimuth accuracy, it is valuable for many purposes.

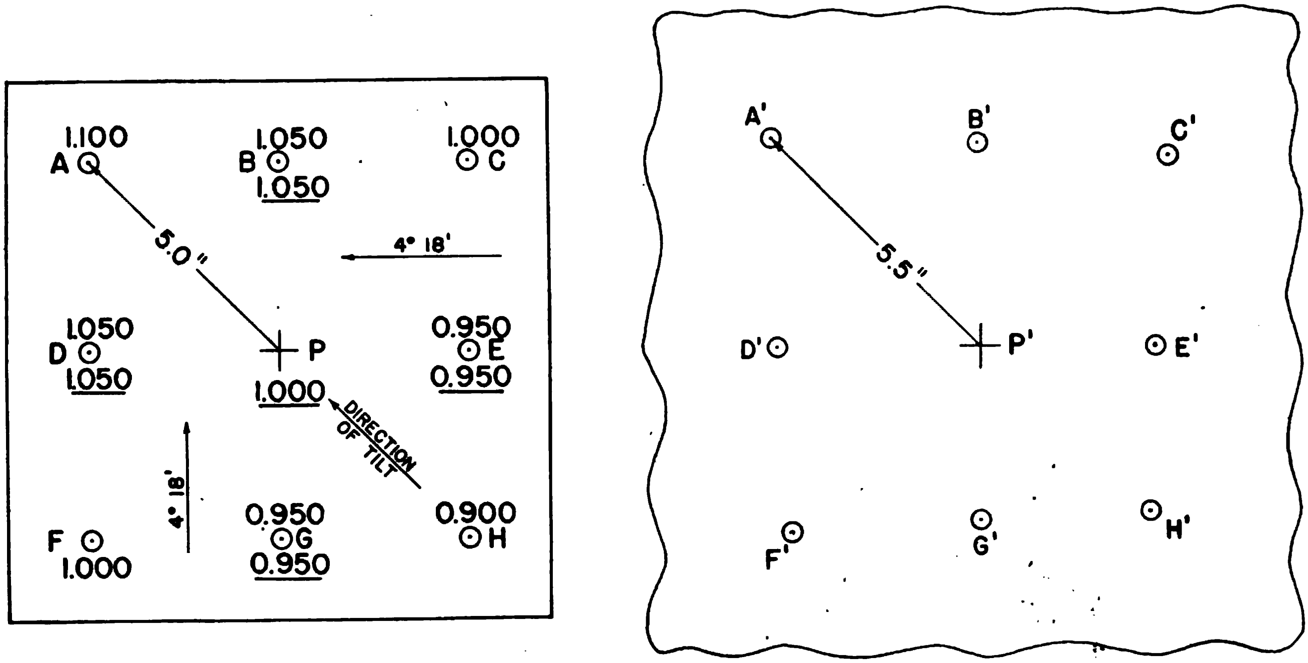
76. Semicontrolled Mosaic

a. General. A semicontrolled mosaic is an assembly of photographs which is laid to ground control augmented by radial-line or slotted-template positions, and in which contact prints of the original photography are used. The semicontrolled mosaic is the type usually made where control is used. It is more accurate than an uncontrolled mosaic but less accurate than a fully controlled mosaic. It may be produced in much less time than the latter, and for most purposes is entirely adequate. As this type mosaic is laid with contact prints, it must be assembled at a scale very near the average scale of the photography.

b. Determination of Scale. The average scale of the photography may be determined by laying one or two trial strips between available ground controls. These are laid as described in paragraph 74*b* except that for scale determination it is not necessary to cut the prints and discard part of the print area. After the strips are laid, the distances between the image points of the control are compared with the corresponding ground distances, to give the average scale to be used in the control plot.

c. Control Plot. The control plot is a radial-line or slotted-template extension between horizontal control positions which have been plotted upon a projection. Since a semicontrolled mosaic is usually assembled upon a rigid mount such as Vehisote, Masonite, or plywood, the projection and control are plotted on this board. The scale of the projection must be the average scale of the photography.

d. Assembly. A semicontrolled mosaic is assembled like an uncontrolled mosaic except that the principal point of each print is located exactly



PHOTOGRAPH PLOT

Figure 40. Method of ratioing points for controlled mosaic.

over its plotted position. The photograph is swung about its principal point to get the best average match with adjacent prints. Mismatches

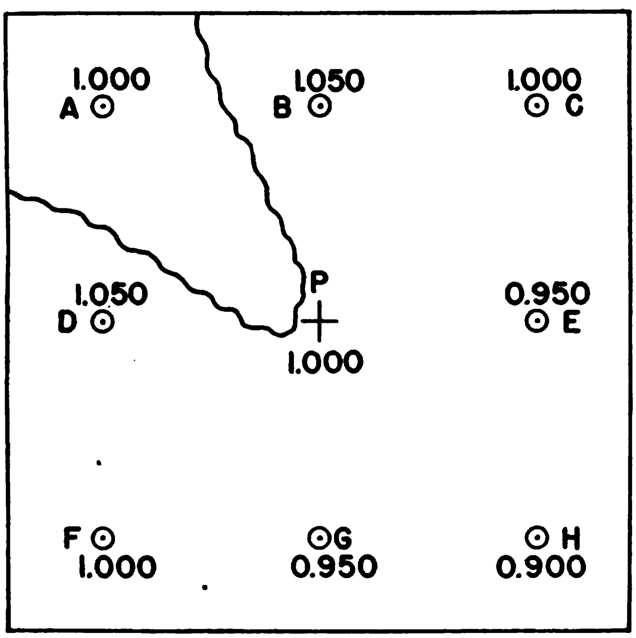


Figure 41. Case of nonuniform ratios.

are allowed to remain, although care is taken in determining the line of match between prints so that important detail is not eliminated. In some instances this may necessitate cutting out small portions of other prints and mounting them over the assembly as patches. A reproduction of a controlled mosaic is shown in figure 42.

e. Accuracy. Since only the position of the principal point of each photograph is laid to radial-line control, that point is the only one correctly located. Its accuracy depends upon that of the radial-line plot. The accuracy of position of other points in the mosaic depends upon the amount of tilt and relief present in the photographs. While mismatched detail in a semicontrolled mosaic may be pictorially unpleasant, it represents the best average position of all image points for this type of mosaic.

77. Controlled Mosaic

a. General. A controlled mosaic is one which is laid to ground control augmented by radial-line or slotted-template positions and in which prints are used which have been ratioed and rectified as shown to be necessary by this control. Thus a controlled mosaic is nearly as accurate as a planimetric map made by the slotted-template method to the same ground control. Although the inherent distortions in the aerial photograph due to tilt and relief cannot be entirely eliminated, even in the most precisely assembled controlled mosaic, they may be lessened to a certain extent by proper procedure and technique.

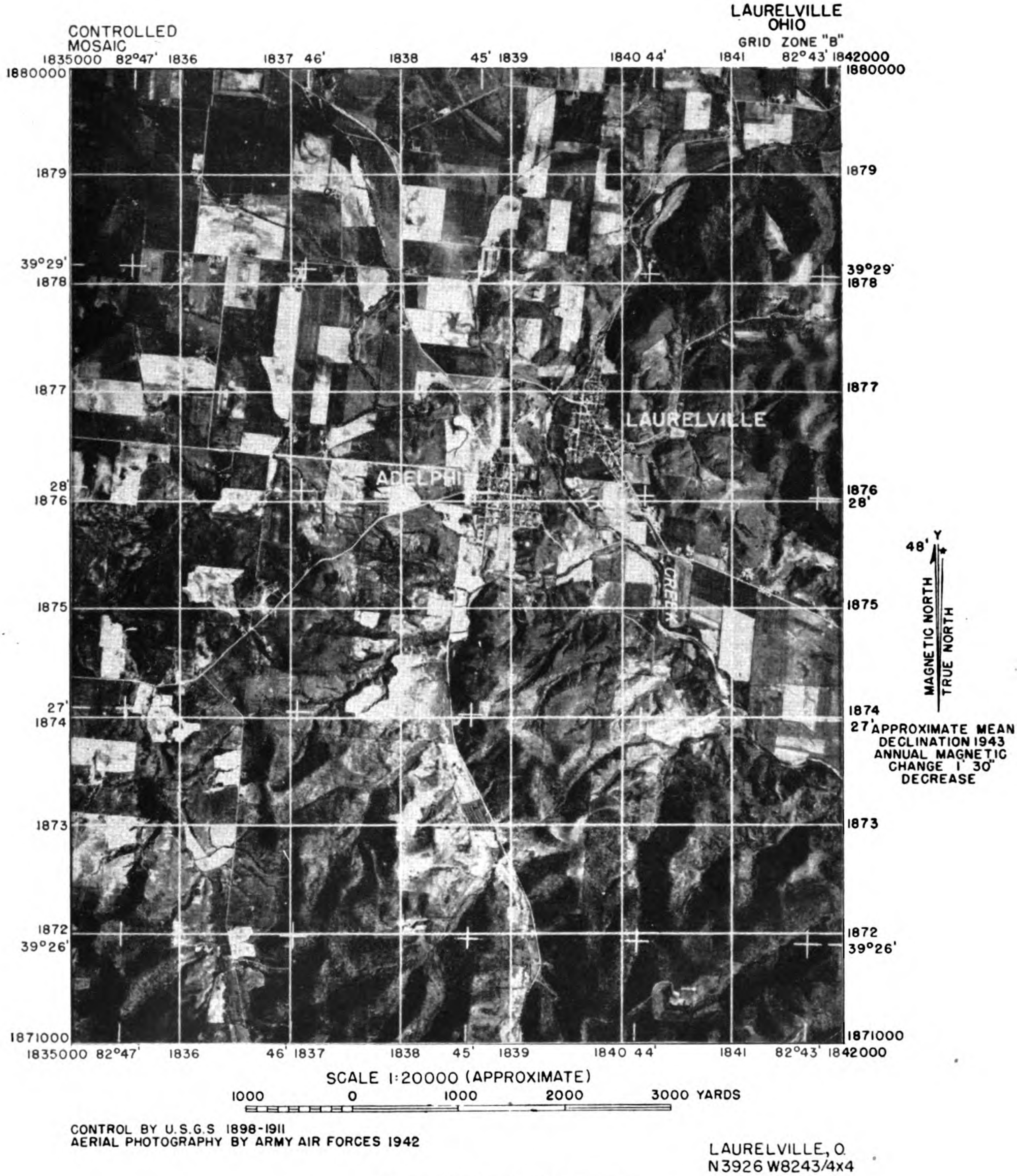


Figure 42. Controlled mosaics.

b. Control Plot. The controlled mosaic is assembled on a rigid mount of Vehisote, Masonite, plywood, or similar material. A projection at approximately the scale of the photographs is constructed on the board, and all available horizontal control which can be identified is plotted. A radial-line or preferably a slotted-card extension of this control is executed to locate the positions of nine points in each photograph.

c. Ratioing Prints. (1) To orient the various

prints so that all image points fit their plotted positions, each print must be rectified and scaled. In a nearly vertical photograph of level terrain, the ratio of the distance between the plotted positions of the principal point and an image point to the distance between the principal point to the image point on the photograph is nearly equal to the ratio of the scale of the plot to the scale of the photograph in the immediate vicinity of that image point. Thus in figure 40, if the distance PA on the photograph is equal to 5.0 inches and the distance $P'A'$ on the plot is equal to 5.5 inches, then the scale ratio of the photograph at point A is equal to 5.5/5.0 or 1.100. Likewise, the scale ratio at point B is 1.050, at C is 1.000, at D is 1.050, at E is 0.950, at F is 1.000, at G is 0.950, and at H is 0.900. The average of the scale ratios at these eight points around the border of the print is the scale ratio at the center of the print, which is 1.000 in the figure.

(*a*) The change in scale ratio per unit distance between any two points across the print is a function of the tilt along the line joining those two points. This ratio change per degree of tilt per inch across the photo is approximately equal to $\frac{\tan 1°}{F}$ where F is in inches. Therefore, for a photograph taken with a 6-inch focal length camera, the ratio change per degree per inch is equal to 0.0029. If the distance across the photograph between points is 8 inches, a ratio change of $8 \times 0.0029 = 0.0232$ across the photograph would be aquivalent to 1° tilt.

(*b*) In practice, both the scale ratios on the leading edge and on the trailing edge of the print and the scale ratios on the two sides of the print are averaged. The difference between the averages on the leading edge and trailing edge, divided by the mean distance across the print between image points, then gives a ratio-change value which may be converted to tilt in degrees. Likewise, the tilt in the direction normal to flight is determined. In the example shown in figure 40 the average of the ratios at the top of the print is shown equal to 1.050, and of those at the bottom of the print equal to 0.950, giving a difference of 0.100. This difference divided by 0.0232, the average distance between scale points being 8 inches, gives a tip value for the photograph of 4.3° or $4° - 18'$. Likewise the tilt of the photograph is computed as $4° - 18'$.

(*c*) With these tilts and tips considered as vector quantities their resultant may be taken as the tilt in the photograph, and the direction of this resultant as the direction of tilt. The tilt is toward the side having the highest ratio, for this side must be enlarged to fit the control plot. These tilts, together with the scale ratio at the center of the print, are the necessary data for making an approximate rectification. A ratio factor of about 0.01 is normally subtracted from the ratio value for the center of the print to allow for stretch in the print. For the example shown, the magnification value to be used in setting the rectifying camera would be 0.990.

(2) The effect of relief prevents the ratioing problem from always working out as simply as illustrated in figure 40. If there were a hill at point A, the ratio at that point could be as indicated in figure 41. Then the scale ratio at point A would be disregarded in determining the tilt or ratio for the print as a whole. Another set of values would be determined, and another print made especially for that section of the mosaic around point A. At times it may be necessary to make as many as five or six ratioed prints from a single negative, and use a small portion of each.

d. Assembly. The procedure for assembly of a controlled mosaic is the same as for that of an uncontrolled mosaic, except that the image points are made to fit over their plotted positions and not so much attention is paid to the match in detail. Usually it will be necessary to use every photograph to obtain satisfactory results. However, where the flight is of uniform altitude over terrain of low relief, it may be possible to use only alternate photographs.

e. Accuracy. Only those points which have been established by the radial-line plot will have the accuracy of that plot. Position errors between these points are caused by relief and will have magnitudes depending upon the amount of that relief. Controlled mosaics to specified accuracies may be laid by proper selection of points for rectification. In terrain having relief, more points are used in the rectification, and several rectifications of the same negative must be made to fit the control in the various portions of the area covered by the print. Mosaics with such refinements will not generally be produced under combat conditions. Hence it cannot be expected that mosaics produced under these conditions will have sufficient accuracy in position for use by the artillery in the same manner as an accurate topographic map. It is often necessary in such cases for artillery to register in each photo section to obtain accurate

fire. Hence, it is desirable that the principal point of each photograph and the outline of each photo section be indicated on the mosaic so that proper corrections for relief displacement can be made. To facilitate identification of each photo section, no attempt should be made to conceal the cut or match lines. The photo prints should be trimmed or featheredged on a regular line.

78. Grid Systems

AR 300–15 prescribes the grid systems to be shown on photomaps. The prescribed grid for controlled and semicontrolled photomaps is the military grid shown on figure 42, and the prescribed grid for uncontrolled photomaps and for those made from single exposures is the point-designation grid shown on figure 38.

79. Marginal Data

AR 300–15 prescribes the marginal data to be shown on all photomaps. For single aerial photographs reproduced as photomaps, this includes: the name of the locality or nearest locality; approximate coordinates of the center of the photograph—military grid preferred; scale of the photograph expressed as a representative fraction; hour of exposure; date of exposure; designation of squadron; and serial number of negative. In addition to the above information, photomaps of mosaics and wide-coverage photographs will include as marginal data: descriptive title, key number, and index; graphic scale in yards; direction of flight—on wide-coverage photographs only; when appropriate, a diagram or statement of any control used, together with a reference to published description thereof; and such other information deemed appropriate.

80. Reproduction

Photomaps are normally reproduced in quantity by lithography. The halftone screen used in lithography limits, to a great extent, the smallest scale at which photomaps may be published. This smallest scale is about 1:20,000 or 1:25,000. At scales smaller than this, so much of the fine photographic detail is lost in reproduction that the photomap loses much of its value. Photographic reproduction is more satisfactory, and scales down to 1:40,000 are practicable. However, photographic reproduction does not lend itself well to large quantity production, and will seldom be used. Therefore, for best results the photomaps should be reproduced at scales of 1:25,000 or larger.

SECTION IX

STEREOSCOPIC MAPPING

81. General

a. USE. The preceding chapters have dealt with the graphical method of compiling maps from aerial photographs. Since this method is a two-dimensional one, its use is confined to the preparation of planimetric maps. Stereoscopic mapping, being three-dimensional, provides a practical means by which topographic maps can be prepared. Many methods of three-dimensional mapping by use of overlapping pairs of aerial photographs have been developed and, with rapid development in aircraft, aerial cameras, and aerial film, the practicability of stereoscopic mapping has become evident.

b. METHODS. Two general methods of stereoscopic mapping with aerial photographs are used by the War Department. These are the use of stereoscopic images obtained by viewing overlapping photographic prints, and the use of such images created by optical reprojection into space.

c. SCOPE. This chapter includes the principles of stereoscopy and its application to topographic mapping by the use of overlapping pairs of photographic prints. The Multiplex method of stereoscopic mapping which uses the principle of optical reprojection is discussed in section X.

82. Stereoscopy

a. GENERAL. The judgment of distance, the relative proximity between objects, and the recognition of sizes and shapes of objects all are due to stereoscopic vision. To see stereoscopically, binocular vision is necessary, since the third dimension is formed only when intersections of rays of light from object to eyes occur. This is illustrated in figure 43*a*. O_1 and O_2 are human eyes. The object, M. is at a distance d. The lines O_1M and O_2M, are rays of light which intersect at M. It is this intersection which establishes the distance to the object. The angle, α, is known as the angle of convergence. It can be seen that the distance to the object M is inversely proportional to the angle of convergence. The smaller the distance from observer to object, the greater the angle of convergence. Relative proximity of two objects is illustrated in figure 43*b*, in which the object N is closer to the observer than M, whereas angle β is greater than angle α. The distance between human eyes varies between 2 and 2⅞ inches. By knowing this and the distance to the object, the angle of convergence can be computed.

b. STEREOGRAM. (1) If, while viewing the image M of figure 43*a*, a transparent screen P were suddenly interposed in the line of sight as shown in the figure, the rays of light passing from M

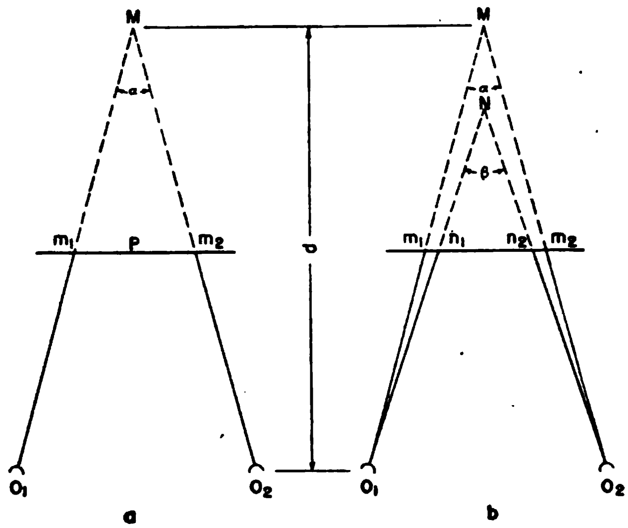


Figure 43. Binocular vision of an object.

to either eye would intersect this screen at m_1 and m_2. If these points were actually recorded on the screen, the point M could be removed but its image would remain at the same position, since the brain fuses m_1 and m_2 at a distance d from the eyes. This distance is a function of the distance between the points, the distance between the two eyes (eye base), and the distance from the screen to the observer.

(2) If a similar screen were placed between point N and the observer in figure 43*b* and the points m_1, n_1, n_2 and m_2 recorded on it, the existence of points M and N would not be necessary for their images to be apparent. The points on the screen in this case would be a stereogram as pictured in figure 44. By concentrating on viewing

m_1 and n_1 with the left eye, and n_2 and m_2 with the right, m_1 and m_2 may be fused into a single mark while n_1 and n_2 also appear as a single image. The resulting images would appear in the same relative proximity as M and N, pictured in figure 43*b*. Thus, by application of this phenomenon, a third dimension can be created by double image representation on a plane surface. The distance between the two images m_1 and m_2 or n_1 and n_2, in figure 44, is known as the absolute parallax of their respective points, M and N.

Figure 44. A stereogram.

c. Stereoscopes. (1) A stereoscope is a simple double lens arrangement which aids stereoscopic perception. By its use, stereoscopic vision is achieved, since the two images are divided distinctly and at the same time the images are fused with a minimum of eye strain. The acuteness of stereoscopic vision may be increased beyond the normal by increasing the length of the stereoscopic (eye) base and by magnifying the image.

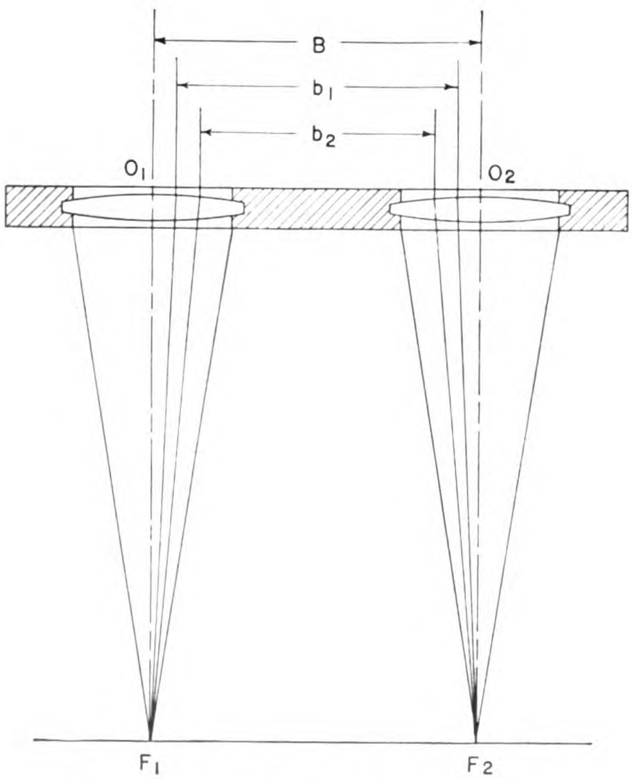


Figure 45. Optics of Brewster stereoscope.

(2) *Types.* All stereoscopes are patterned from the Brewster and Helmholtz types.

(*a*) The Brewster type stereoscope illustrated in figure 45 consists of two convex lenses or two prisms mounted with their optical axes parallel and with the distance between centers of the lenses about 15 percent greater than the eye base of the observer.

(*b*) The Helmholtz stereoscope illustrated in figure 46 is a reflecting type, usually made of mirrors or of mirrors in combination with lenses. Use of the mirrors facilitates lengthening stereoscopic base, and the lenses afford the desired magnification.

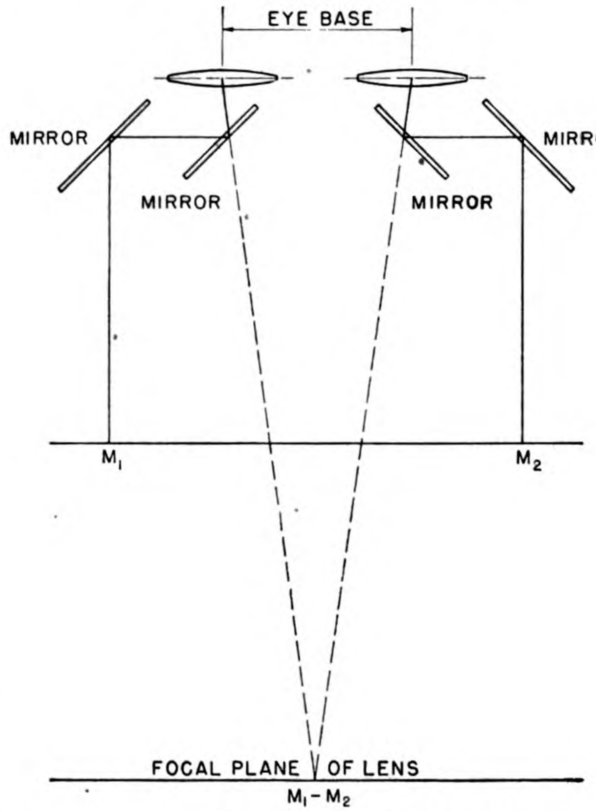


Figure 46. Optics of Helmholtz (reflecting) stereoscope.

d. Application to Aerial Photographs. To apply the principle of stereoscopy to the use of aerial photographs, it is necessary that images be represented on two photographs taken from different air stations. The camera records the positions of images on overlapping photographs at two different instants, whereas in figure 43*b* the double images of points M and N can be assumed to have been recorded by both cameras—the human eyes—at the same instant. In figure 47 two overlapping photographs are pictured. Points M and N on

the ground are recorded at m_1 and n_1 on photograph No. 1 and at m_2 and n_2 on photograph No. 2. The two photographs are separated in a manner which permits viewing m_1 and n_1 with the left eye, and m_2 and n_2 with the right eye, similarly to the sterogram in figure 44. In the double recording of an image on two overlapping, truly vertical photographs taken at the same altitude it is significant that each pair of images is equidistant from the base line of the photographs. Therefore, in the figure the line connecting n_1 and n_2 is parallel to the line connecting m_1 and m_2.

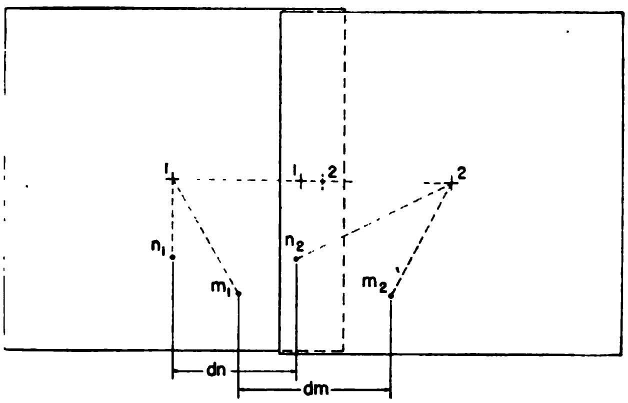


Figure 47. Stereoscopic vision from overlapping photographs.

This principle accounts for the ability to orient a stereoscopic model by removal of "y" parallaxes, which is discussed in section X and explained in detail in TM 5–244. Similarity can be noted between the parallaxes d_n and d_m shown in figure 47 with those shown in the stereogram of figure 44, whereby the fusion of points creates the image of point N nearer the observer than point M. Since the photographs contain an infinite number of point images, the relative proximity of all points in a correctly oriented pair of overlapping photographs will be apparent, and stereoscopic vision is realized.

e. **Theory of Elevation Computation.** In figure 48 is shown the profile along the principal plane of the two photographs of the landscape shown in plan view in figure 47. Point M appears on negatives I and II at points m_1 and m_2, respectively, and on the corresponding positives at positions m and m'. In this figure a line parallel to Mn_2 is drawn through O_1. The triangle $m''O_1m$ is similar to triangle O_1MO_2. From this:

$$\frac{pm}{B_m}=\frac{f}{H-h} \text{ and } pm=\frac{fB_m}{H-h} \qquad (1)$$

where H is the altitude of the camera above sea level, h is the elevation of the point M above sea level, and B_m is the air base or distance between camera stations. The distance p_m is the absolute parallax of point M. Similarly, the absolute parallax of point N is p_n as shown. Since the values of H, f, and B are constant for any two overlapping photographs, it can be seen from the above equation that by measuring the absolute parallax of any image its elevation can readily be computed. It is this equation upon which the operation of the stereocomparagraph is based, as discussed in paragraph 85.

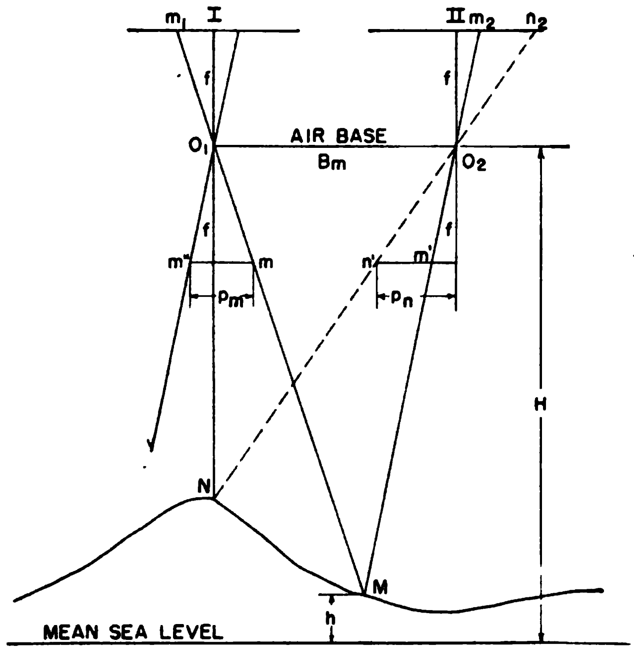


Figure 48. Computation of absolute parallax.

83. Stereoscopic Vision in Form Line Sketching

a. **General.** Stereoscopic vision of aerial photographs affords the ability to view a large section of the terrain in perspective. As a result, ground formations are readily visible. The detail of these formations may be sketched while viewing two overlapping photographs through a hand stereoscope to show the general shape of the terrain.

b. **Application to Field Survey Topography.** The methods of preparing contour maps prior to the stereoscopic use of photographs were generally those of the plane table and of transit topography. The plane-table method afforded ground view of the landscape and permitted plotting contours in nearly correct form. The transit method, however, necessitated securing numerous

elevations of points in the field, from which contours were interpolated on the map sheet as part of the office compilation. The transit method permitted no means of depicting true ground formations with contours and, as a result, the maps compiled by this method were not good topographic maps. The stereoscope and aerial photography, however, in conjunction with transit topography, are means of improving the system, since with controlling elevations marked on the photographs the interpolated contours can be made to fit the true shapes of the ground. Therefore, if no other stereoscopic plotting instruments are available, the hand stereoscope should be used in conjunction with all contour or form-line sketching which involves the use of aerial photography. The stereoscope and aerial photography also afford an advantage in plane table topographic mapping, since the perspective view of large areas permits a more dependable interpretation of general ground formations than can be acquired by panoramic observation.

c. Form Lines. In military operations it is often necessary to effect some sort of portrayal of relief of an area without time or means of securing vertical control. This is done by sketching form lines on the photographs or on transparent overlays. Form lines do not represent any order of vertical accuracy, but they afford a means of showing up and down grades as well as high and low features in the area. Form lines are plotted similary to contours, but the controlling elevations are assumptions based on logical interpretation of the terrain. Primarily, a careful study of the terrain is made, noting especially the drainage system. Then, based on the most intelligent conclusions, definite assumed elevations are assigned to maximum and minimum elevations in the area. Based on these, definite elevations are assigned to all critical points such as ridge tops, stream intersections, and sudden changes in slopes. With this assumed control network, form lines may be sketched between control points with the aid of a simple stereoscope in a manner similar to that discussed in *b* above. When one or two ground control points are available, they may be used as a basis upon which the control network for form-line sketching is assumed.

84. The Stereocomparagraph

a. Use. The stereocomparagraph is used to compile contour information to supplement planimetry compiled by other graphical methods in order to produce a topographic map. Because of the limitations of this instrument it is used primarily for the preparation of reconnaissance type maps rather than for those having a higher order of accuracy. However, maps of greater accuracy may be produced by proper application of the principles involved and proper modification of the stereocomparagraph procedure.

b. Principles. The stereocomparagraph affords the means of measuring differences in elevations by direct measurement of differences in absolute parallax, and of sketching planimetry and contours directly from the stereoscopic model viewed under its stereoscope. The stereocomparagraph, as shown in figure 49, consists essentially of a stereoscope, a measuring system, and a drawing attachment. The stereoscope is the reflecting type, with a pair of matched lenses which permit magnification of the detail of the photographs. This instrument is a modification of the Helmholtz stereoscope whereby a small dot appears in the center of each of two lenses which contact the photographs (one lens appears below each eye). This modification can be seen by comparing figures 46 and 50. In figure 50 the lenses containing the dots are an integral part of the instrument. The right lens may be moved horizontally so that the dots fuse, as explained in paragraph 82, and as a result appear as a single point. When the distance between the two dots on the lenses is varied, the apparent distance from the observer to the fused image of the two dots is changed. Therefore, when the instrument is aligned over a pair of overlapping photographs which are stereoscopically visible, the floating point can be brought to rest at any point on the ground surface of the stereoscopic model. A micrometer attached to the movable lens affords means of measuring the horizontal distance between dots. If, then, the micrometer readings are recorded when the floating point is brought to rest at various points on the model, the differences in readings are measurements of the differences in elevation. The lenses containing the dots, and the micrometer which affords measurement between them are indicated in figure 51.

(1) *Alignment.* During the operation of the stereocomparagraph, it is necessary that the eye base or line connecting the dots on the lenses be parallel to the air base of the photographs. This alignment is accomplished first by properly orienting the photographs under the stereocompara-

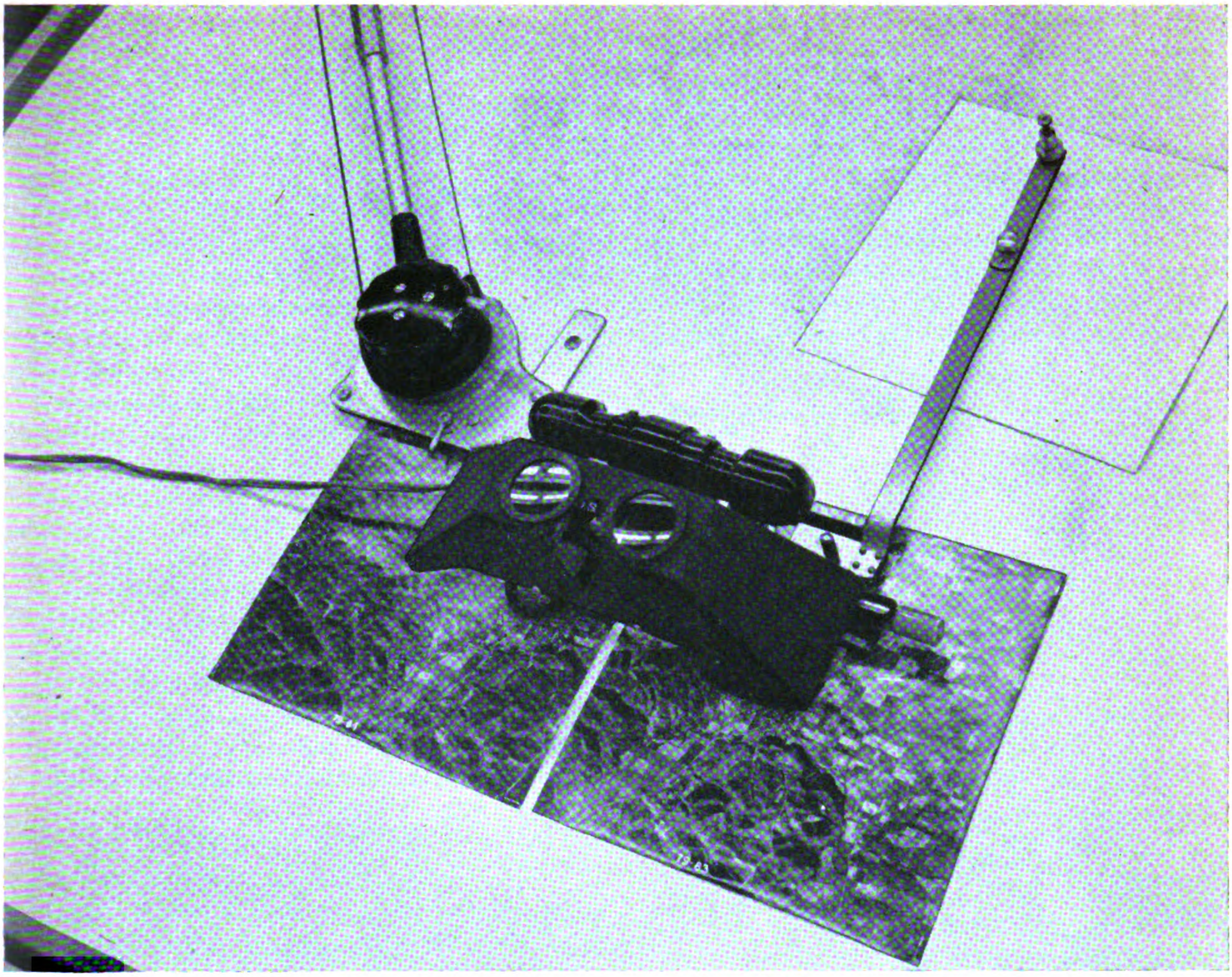


Figure 49. Stereocomparagraph.

graph, and second, by an attachment on the instrument which permits connection to a standard type drafting machine or any other suitable parallel-motion mechanism and insures maintenance of the instrument's adjustment once it is established. Small residual "y" parallaxes are removed by an adjustment of the right lens actuated by the thumbscrew.

(2) *Drawing attachment.* Plotting of detail is done by a drawing attachment consisting of an arm connected to the base of the stereocomparagraph at the end of which is mounted a special pencil. The pencil arm has a ball-pointed rest to hold it at the correct height above the paper.

c. Parallax Tables. By use of equation (1) in paragraph 82*e*, elevations and elevation differences may be computed when measurements of parallax are made with the stereocomparagraph. Tables from which data can be read directly are prepared for use between probable maximum and minimum flight altitudes above the terrain. The computations of the tables are based on the differential of the equation given in paragraph 82*e*. By converting the measurement of the air base into terms of distance on the photographs, this differential equation is simplified into the following form:

$$\Delta p = \frac{Bm \cdot \Delta h}{H-h}$$

wherein B_m is the distance between principal points in millimeters, Δh is the desired contour interval in feet, $H-h$ is the flight altitude in feet above the elevation of the contour, and Δp is the differential parallax in millimeters. The tables are computed for a value of B_m of 100 millimeters. In a specific pair of overlapping photographs, the

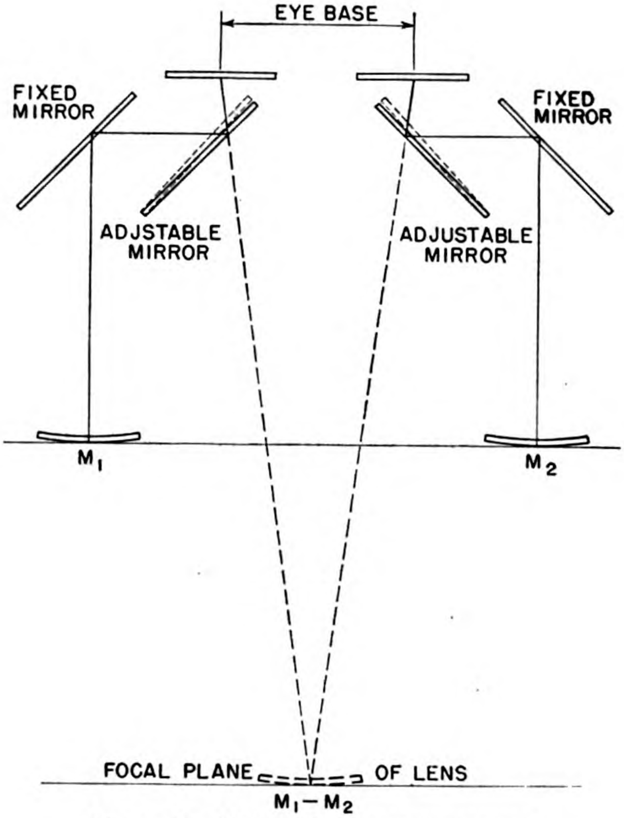


Figure 50. Optics of stereocomparagraph.

value of Δp read from the table is multiplied by the ratio of the measured B_m to 100 as the value of Δp will correspond to that case. Details of the computations and use of the tables will be found in TM 5–230.

85. Control Requirements

a. GENERAL. Mapping with the stereocomparagraph is essentially a method whereby contours are added to the planimetric base prepared by the radial-line system. Since control requirements have already been discussed for planimetric mapping in section VI, the requirements discussed in this section will deal only with those for vertical control.

b. VERTICAL CONTROL. (1) In plotting contours by the stereoscopic viewing of photographic prints many sources of error exist. The stereoscopic model is never truly parallel to the sea-level datum. The scales of photographs may vary and, with other inherent distortions, plotting contours without ample control is undependable. The use of the stereocomparagraph, eight points per model, is considered necessary to give the same vertical accuracy attained by multiplex mapping

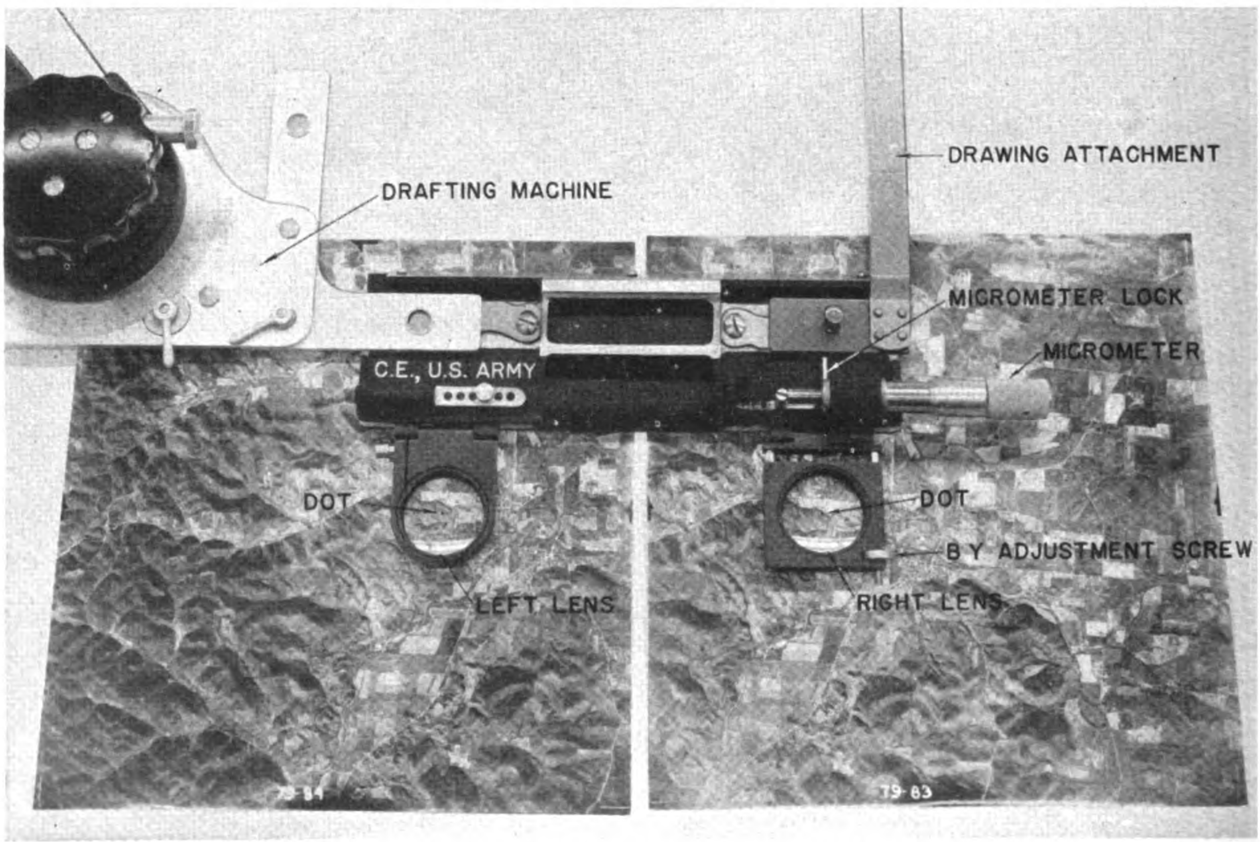


Figure 51. Base of stereocomparagraph.

with four points, one in each corner of the model. Figure 52 illustrates the optimum arrangement of these eight points.

(2) In this method, the general rule that accuracy is proportional to the number of control points is especially true. The nature of the terrain is also significant in determining the amount of control necessary. With greater relief, more points are required. The points should be spaced uniformly and in positions which, as far as possible, afford common use for adjacent models. In this manner continuous mapping will be made possible and matching of contours from model to model will be simplified. Such density of vertical-control points requires a great amount of field work. This is one reason why the stereocomparagraph is not normally used for accurate mapping. Since the primary use of the stereocomparagraph is in reconnaissance mapping, the depiction of topography must usually be based upon a limited amount of vertical control. This means that form-lining by means of the stereocomparagraph must suffice.

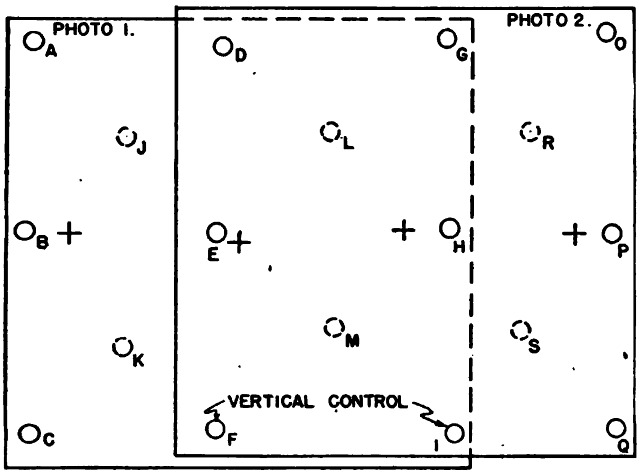


Figure 52. Most desirable vertical control lay-out for stereocomparagraph.

86. Topographic Mapping.

a. Plotting Planimetry. Although relief distortions can be overcome by stereoscopic plotting of planimetry, this advantage is not gained in the use of the stereocomparagraph. In this instrument, the left dot on the left lens is fixed, and the floating point is formed by fusion with a movable right-hand point. But since the left point is stationary, tracing planimetric features from the model amounts to reproducing the left-hand photograph, or a perspective projection of the photograph. It will be shown in section X that stereoscopic mapping by optical reprojection affords a reproduction of the model in orthographic projection. Plotting planimetry with the stereocomparagraph presents no advantages except that it might be convenient to trace the detail with the aid of streoscopic vision. In either case, the detail may be transferred to the base sheet in the manner described in section VI. However, this process should be deferred until contours are added to the planimetry so that both can be transferred at once, as explained in the following paragraphs.

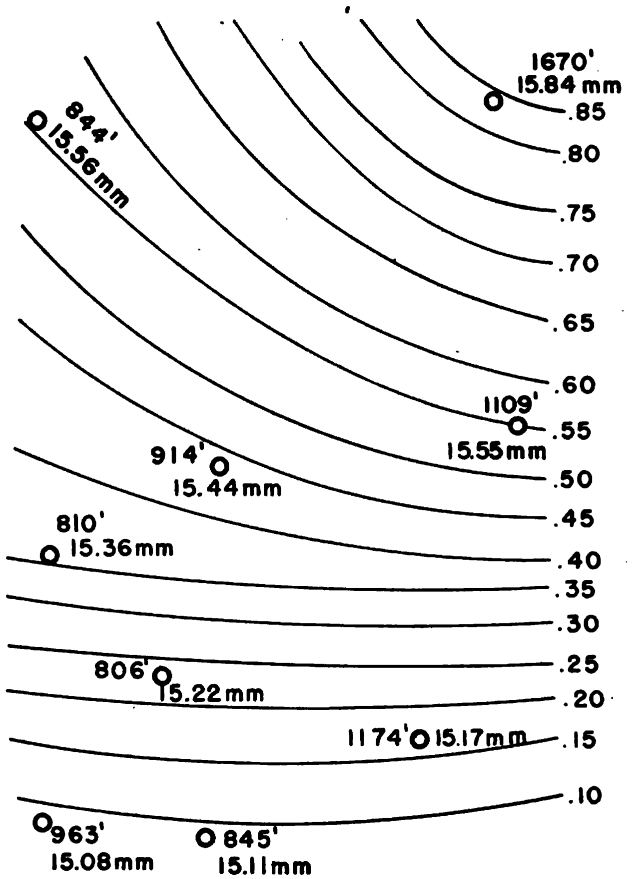


Figure 53. Typical correction graph.

b. Plotting Contours. (1) *General.* (*a*) If the photographs oriented under the stereocomparagraph were truly vertical, and other distortions were at a minimum, then with vertical control points in the four corners of the model, contours could be plotted consistently with the control necessitating little correction. Since this condition is not probable, the lack of parallelism between the datum plane of the model and the sea-level datum must be corrected and since no provision

exists whereby the datum plane of the model can be varied, the correction must be applied by correction graphs.

(*b*) *Correction graphs.* A correction graph is constructed by using the differences in micrometer readings derived from the true elevations of vertical control points and the observed readings in the datum of the model. Now, if the datum of the model is parallel to sea level and there are no other distortions, the observed micrometer readings of the control points are equal to the computed readings. If their differences were zero, no correction would be necessary. As this rarely occurs, correction graphs similar to that shown in figure 53 are necessary. The lines shown are interpolated between control points as though they were contours with an interval of either 0.05 or 0.10 millimeter, depending on the density of the graph lines. The control points for this graph are the differences in the computed and the observed micrometer readings of the vertical control points. The amount of tip and tilt is apparent from the amount of relief represented in the graph. The correction graph, as plotted, serves as a means of correcting not only for tilt and tip but also for all other distortions which may be present, such as variation in scale between the two photographs, and irregular shrinkage of the prints. The accuracy of this graph, like the accuracy of the contours to be plotted, depends upon the number of vertical control points used.

(2) *Procedure.* (*a*) Since no material advantage is gained by planimetric plotting with the stereocomparagraph, the detail represented by the left-hand photograph oriented under the instrument should be considered the planimetric plot to be transferred to the base sheet. The object at this stage is to add contours to this plot. Since these must be plotted by the pencil on the drawing arm of the instrument, a transparent template, which will later become an overlay of the left-hand photograph, is used as a drawing medium. All existing control is plotted on this template so that it may later be registered properly on the photograph.

(*b*) To plot the contours, the correction graph should be oriented over the left-hand photograph so that it becomes a part of the model and therefore presents a convenient means of making corrections during the contouring process. For this purpose the graph should be made on transparent material. It is advisable to contour the model from the lowest elevation to the highest. The approximate position of the lowest contour to be plotted, and its micrometer reading, are determined. The correction-graph reading nearest to the location of the contour to be plotted is added algebraically to the micrometer reading. The readings which correspond to contours to be plotted are taken from the parallax tables corrected for the measure B_m of the model. With the micrometer set to the adjusted elevation, the instrument is moved until the floating point contacts the ground. Then the instrument is moved continuously so that the floating point is constantly in contact with the ground, while the pencil point of the instrument is lowered to record the contour on the template. When the floating point crosses a correction-graph line, the micrometer reading is increased or decreased, as the case may be, by an amount equal to the graph-line interval. Other contours are traced in a similar manner after correcting their initial micrometer readings by the correction-graph reading. The position of the right dot may be locked by the lock screw, as indicated in figure 51. In the course of the contour-plotting process, the two dots may become separated in the "y" direction, that is, "y" parallax may become apparent. This parallax can be removed by using the "BY" adjustment screw on the right lens, as indicated in figure 51.

c. Compilation. When the contour plotting is completed, the product will be a transparent template containing the contours which can be overlaid on the left-hand photograph. Since this photograph contains the radial control points, the planimetry and contours may be transferred to the base sheet by the methods prescribed in section VI.

d. Checking. After compilation, the contours should be checked for agreement with planimetry, especially the drainage. Examination of the photographs under a hand stereoscope will show whether the ground shapes have been depicted correctly. This checking operation can be performed at the same time that the planimetry is checked for completeness as discussed in section VI.

87. Practicability of Stereocomparagraph

The stereocomparagraph is a simple stereoscopic plotting instrument which can be used for the preparation of topographic maps. Because of its principles, this instrument is not suitable for the preparation of maps of a high degree of accuracy unless special measures are adopted to assure this

accuracy. This would involve the establishment of a sufficient number of minor control points by the radial-line method, and adjustment of planimetry and contours to these points. A great density of vertical ground control is necessary to achieve great accuracy. Where maps of a high degree of accuracy are desired, the Multiplex method is normally used, since the objective can be accomplished far more efficiently. This will be made understandable by comparing the stereocomparagraph process of mapping with that of the Multiplex, explained in section X. The stereocomparagraph is admirably suited for the preparation of reconnaissance type topographic maps where accuracy is not of prime importance. Because of its small size and portability, it is suitable for extremely mobile units. Since photographic prints are used, a map can be made by the stereocomparagraph in a short time. Other advantages of the stereocomparagraph are that it can be used for rapid measurement of elevation differences, and that novices can become proficient in its use relatively quickly.

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SECTION X

MULTIPLEX MAPPING

88. General

a. Method. The Multiplex method of mapping, also based upon stereoscopic principles, is the most precise one available to the War Department for preparing topographic maps from vertical aerial photographs. Being an optical-projection system, it employs methods which eliminate distortions inherent in other mapping methods. Precision in mapping with this equipment is limited by the density of control, the training of the operators, and their care in manipulating the equipment.

b. Use. The Multiplex method is suitable for preparing of topographic maps of all scales, the largest scales being limiting by the lowest altitude at which mapping photography can be obtained. It is also suitable for large scale planimetric mapping where great position accuracy is desired. Since it is the only mapping method employed by the War Department by which contours can be plotted from aerial photographs to a high degree of accuracy, it is used whenever topographic maps are to be made. Publication scales at which military maps prepared by the Multiplex method are reproduced vary from 1:20,000 to approximately 1:125,000.

c. Scope. This section discusses primarily the general theory of the Multiplex method, but also includes a discussion of the application and planning of Multiplex mapping projects. A detailed description of the principles and operation of the Multiplex is contained in TM 5–244.

89. Principles of Multiplex

a. General. (1) Stereoscopic methods of mapping like those of the stereocomparagraph form stereoscopic models which are not true reproductions of the model in nature, and create their models upon a fixed plane with respect to the photographs. In contrast, the Multiplex method affords means of creating a true stereoscopic model in space and of intercepting that model by a horizontal plane surface which can be varied in elevation, the stereoscopic model itself being fixed. The variable plane affords a means of deriving accurate horizontal and vertical measurements from the model.

(2) The stereoscopic model is created by optical projection of two consecutive overlapping pictures properly oriented to each other. Each picture is an exact duplicate in miniature of the original photograph which was formed by the cone of rays reflected from the ground to the aerial camera. The model is actually formed when the projectors are so oriented that all corresponding rays from each of the two projectors intersect in space. These ray intersections are not all in the same horizontal plane, except for those points having the same elevation above the datum. But a series of horizontal planes, passing through the model spaced at infinitely small distances apart, contains all the intersections of corresponding rays of a correctly oriented model.

(3) The horizontal plane surface, upon which the model is viewed, is varied in elevation so that it contains the intersection of the corresponding rays to any desired object. To view this model, use is made of filters of complementary colors. One picture is projected through a red filter and the other through a blue-green one. By viewing these two projections through spectacles of corresponding complementary colors, the mind of the operator fuses them so that a miniature stereoscopic model is apparent. This model is similar to one formed when viewing an anaglyph.

b. Multiplex Unit. There are 2 types of Multiplex equipment, the wide-angle and the normal. These terms refer to the angle of coverage used in the aerial camera and the Multiplex equipment. All references will be to the wide-angle type unless otherwise stated, since it has practically replaced the normal type. A multiplex unit is pictured in figure 54. The projectors by which optical projections are made are shown on the Multiplex bar. The instrument containing the horizontal plane surface upon which the model is viewed is shown below the projectors. This is the Multiplex tracing table. The small table on the floor to the right contains a transformer which reduces 110- or 220-

volt current to approximately 20 volts, and a rheostat-controlled switch box which controls the current to 10 outlets along the bar on 4 different circuits. The boxed unit on the floor to the left is a blower type cooling unit which blows air through the projector-lamp housings for cooling purposes. The Multiplex bar pictured is the normal size. It permits a setting of 7 models or 8 projectors. For long extensions, a double bar is used which permits setting 16 or 17 models.

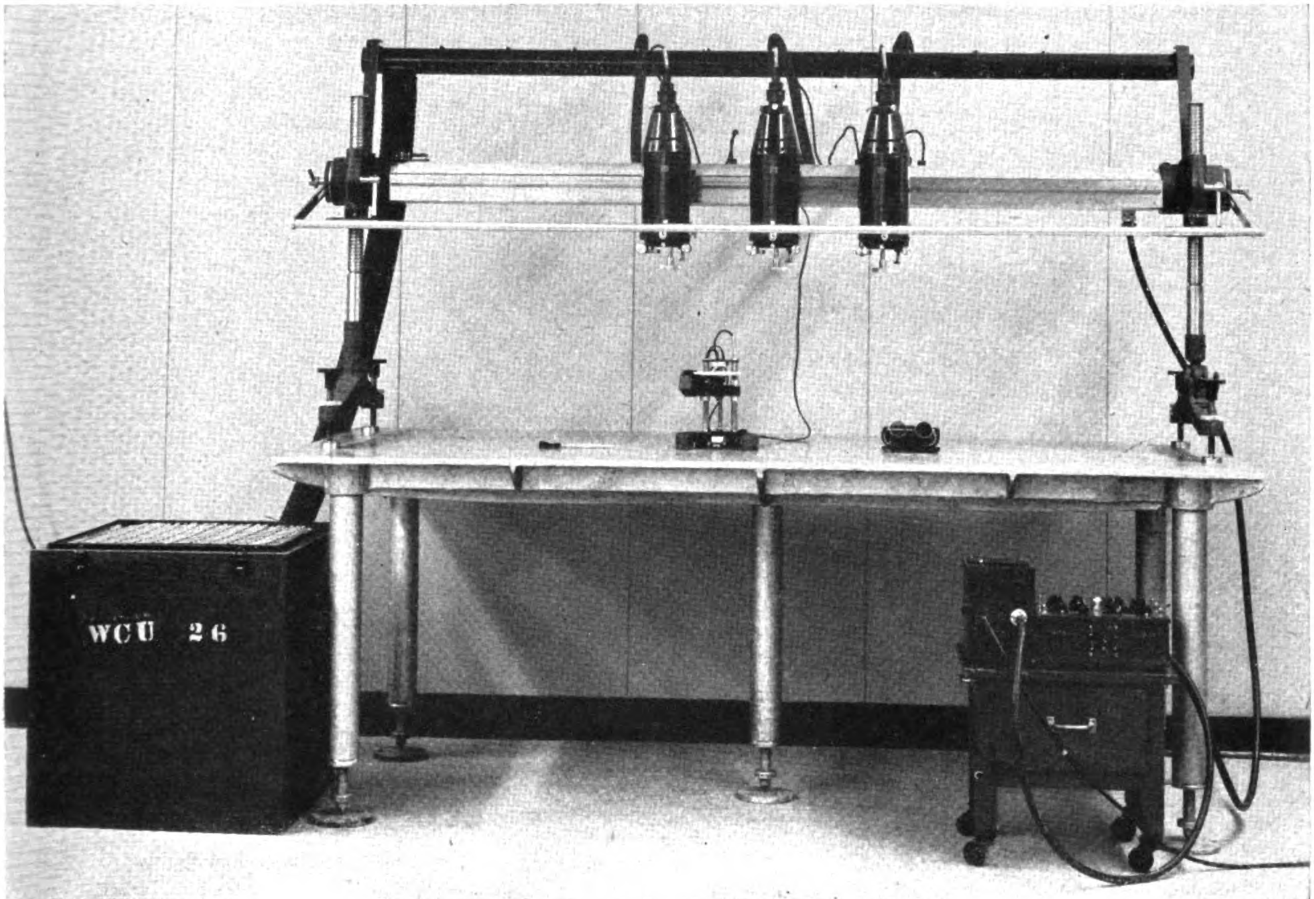

Figure 54. Multiplex unit set up ready for operation.

c. MULTIPLEX TRACING TABLE. (1) One of the factors which distinguishes the Multiplex from other stereoscopic mapping methods is the Multiplex tracing table by which the stereoscopic model is actually measured and by which features of this model are transferred orthographically to a map plane. This table, upon which the Multiplex model is projected, is shown in figure 55. In the figure the operator's finger is placed on the vertical-motion screw which moves the table-top platen up and down. By the vertical movement of the table-top platen the stereoscopic model can be made to appear deep down into the frame of the table, or on the surface of the platen.

(2) To reference the platen to the model there is a pin hole in the center of the platen as shown in the figure, which is illuminated by a small electric bulb, giving the appearance of a pin point of light. As the height of the platen is changed in the model, the pin point of light will appear to be floating above, sunk below, or resting on, the model. The point, then, becomes the "floating point," and since the entire tracing table can be moved horizontally as well as the platen can be moved vertically, the floating point can be brought to rest at any position in the model. Thus, if the stereoscopic model created is an accurate miniature of the corresponding portion of the earth's surface, it is possible by means of the floating point to measure horizontal distance and vertical heights within that model. This is exactly what is done in compiling maps by the Multiplex.

(3) In the figure is shown the location of a vertical metric scale on which a vernier attachment

permits reading to 0.1 millimeter. When the floating point is brought to rest on the ground, the reading of the scale is a measure of the elevation in the model. The pencil point shown is aligned directly below the floating or marker point. When the point is brought to rest on the ground, the pencil point is lowered, and records the position on the drawing medium below. Contours are drawn by clamping the table top at the desired elevation and keeping the marker point in contact with the ground surface while tracing throughout the model with the pencil in contact with the drawing medium. Planimetric features are drawn by tracing them with the marker point while the pencil is lowered to record the features on the map. To record a true orthographic projection the marker point must be kept in contact with the ground while plotting planimetry.

d. Advantage of Multiplex Method of Plotting Planimetry. With the free-floating point used in tracing planimetric features from a Multiplex model, relief distortion is completely overcome. In mapping with the stereocomparagraph, because of the fixed left-hand dot the planimetry plotted is a reproduction of the left-hand photograph and contains all the relief distortions inherent in any perspective photograph. In the Multiplex method these relief distortions are overcome by "following the relief." Therefore, the resulting positions of the features are based on the true data in which the features lie, rather than on a common datum for all features, as discussed in section V.

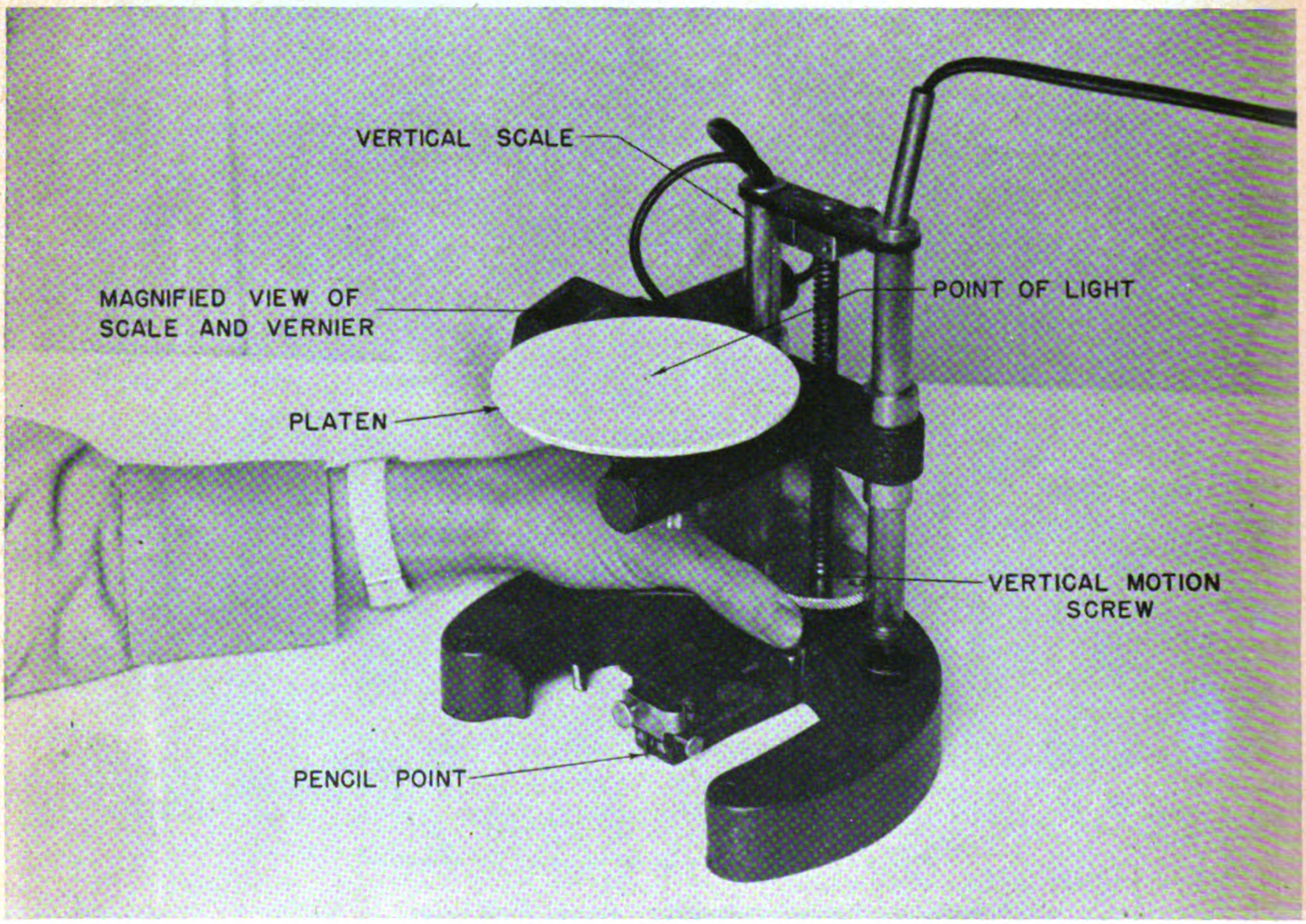

Figure 55. Multiplex tracing table.

90. Photographic Requirements

a. General. The stereoscopic views produced by Multiplex projection must be true reproductions of nature, since the topographic features traced therefrom must be in true relationship to each other to produce an accurate map. To achieve this it is necessary that the photography be performed with accuracy. Requirements for aerial photography

stated in section II are applicable, but particular emphasis is placed upon three features: the aerial camera used, the flatness of film at the instant of exposure, and the use of topographic-base aerial film. The last two are requirements for all mapping methods, but lack of flatness of the film at the instant of exposure and the use of regular base film has more effect on the Multiplex method because the distortions produced are made readily apparent by the mismatching of corresponding image rays in the projection when the stereoscopic model is being formed. Since these distortions produce greater elevation errors than position errors, they can sometimes be ignored for planimetric mapping, but never for topographic mapping.

b. Types of Camera Suitable for Multiplex. Certain aerial cameras available in the air forces are suitable for use with Multiplex equipment. Wide-angle Multiplex equipment is designed around the 6-inch focal length Metrogon, wide-angle lens, which is used in three different cameras having suitable characteristics for Multiplex work, all of which expose a negative 9 inches square. The T–5 camera is best suited for Multiplex work because of its precision construction. However, both the K–3B and K–17 cameras with the 6-inch wide-angle lens have been used satisfactorily with the Multiplex equipment. The normal Multiplex equipment was designed for use with both the central chamber of the T–3A camera and the 8¼-inch K–3B camera. The T–3A has a nominal focal length of 6 inches, and exposes a negative 5.5 inches square. The K–3B has a focal length of 8¼ inches and exposes a negative 9 inches square, although only an area 7 by 9 inches may be used in the Multiplex equipment.

c. Flatness of Film at Instant of Exposure. The pressure plate in the aerial camera normally keeps the film flat during exposure. Any failure of the vacuum supply, or clogging of the vacuum lines, causes the film to take a warped shape which prevents a true perspective being recorded on the film and makes it useless for Multiplex topographic mapping. The warping may not be enough to throw the images out of focus, but it will be apparent when forming the stereoscopic model by parallax or failure of corresponding rays to intersect in a point, or distorted elevations in the model. Sometimes, variation in the scaled distance across the same portions of several negatives will reveal this warping.

d. Topographic-base Film. As explained in paragraph 16*b*, topographic-base film has been manufactured in such a manner that its shrinkage is uniform in all directions and small in amount. The edge of this film is always marked "Topographic Base." Regular aerial film does not have such uniformly small shrinkage characteristics and the consequent effect of distortion will be apparent as parallax or distorted elevations in the model. Only topographic-base aerial film should be used when mapping with the Multiplex equipment.

91. Control Requirements

a. General. (1) A Multiplex model is only as accurate as the control to which it is scaled and horizontalized. The accuracy of the model depends on three main factors: the accuracy of the position of the control points in relation to the other control points, the identification of these points on the photographs, and the density of the control. The required limits of accuracy in most military maps do not demand extreme density of control and accuracy. The requirements for identification of control are always strict, regardless of density.

(2) In stipulating control requirements, advantage of the accuracy of the Multiplex should be taken so that the amount of control will be minimized. In Multiplex bridging, position and elevation accuracies depend upon the interval between bands of control. The highest order of accuracy in Multiplex plotting would be achieved with control existing in every model. This is impractical for most military needs, although in civil mapping, vertical control is usually required in four corners of every model. In preparing military maps, great accuracy is needed to meet the requirements for artillery fire, which calls for position accuracy within 33 yards and elevation accuracy within 25 feet at publication scales of 1:20,000 and 1:25,000. The precision characteristics of the Multiplex permit relatively long control extensions so most map accuracy will be within those limits.

b. Horizontal Control. (1) In horizontal bridging, the interval between bands of control which will permit required position accuracy is far greater than that required for vertical bridging. To satisfy requirements for position accuracy in artillery fire, horizontal control is required at intervals of 11 pairs of photographs for a plotting and publication scale of 1:20,000. However,

for smaller publication scales, that interval may be increased without sacrificing accuracy. Other considerations make it desirable to establish control at certain designated intervals. In mapping 15-minute quadrangles at a plotting scale of approximately 1:20,000, it is more convenient to place control on either end of the quadrangle, thus necessitating control at intervals of approximately every seven models.

(2) Another influencing factor in the selection of the interval between bands of control is the size of the Multiplex bar. On a single bar, it is not possible to bridge the 11 models, which is the length of bridge permissible to achieve the desired position accuracy, but, since 7 models can be bridged conveniently, the quadrangle interval is most practical in this case. With the use of the double bar, intervals between control may be as great as 17 models. This may be a practical interval when compilation scales are to be greatly reduced to small publication scales.

c. Vertical control. Since vertical accuracy is more critical, smaller intervals between vertical control are required. With constant flight altitude, corrections may be applied to observed elevations between bands of vertical control so that errors can be reduced to reasonable limits. Accordingly, to meet the vertical accuracy requirements for artillery fire, vertical control may be spaced at intervals of three or four models. Since vertical accuracy is independent of publication scale, this spacing of bands of control is required to meet it.

d. Density. Traverses and level lines are most economically planned when they are perpendicular to the lines of flight. When new control is to be planned, the density of control along these lines should be sufficient completely to control the pairs of photographs through which the lines pass. In other words, it is desirable to establish traverse lines so there will be at least two points for each strip. A point located in the sidelap can be used for two strips. Elevation points should be established in the four corners of the pair of photographs through which the level line passes, so that sufficient control will be available to horizontalize that model properly. In many instances vertical control points will serve two adjacent strips. Since these lines must be traversed, and stations or turning points established along that line, it is not much more difficult to pick in sufficient density stations and turning points which can be identified upon the photograph for use as control points. Such a procedure will take little extra time and will assure a better control network upon which to base the Multiplex bridge.

92. Camera, Printer, Projector Relationship

a. General. To reproject the photographs to form a stereoscopic model, the size of the aerial negatives must be reduced by the reduction printer to fit into the Multiplex projectors. Of basic sig-

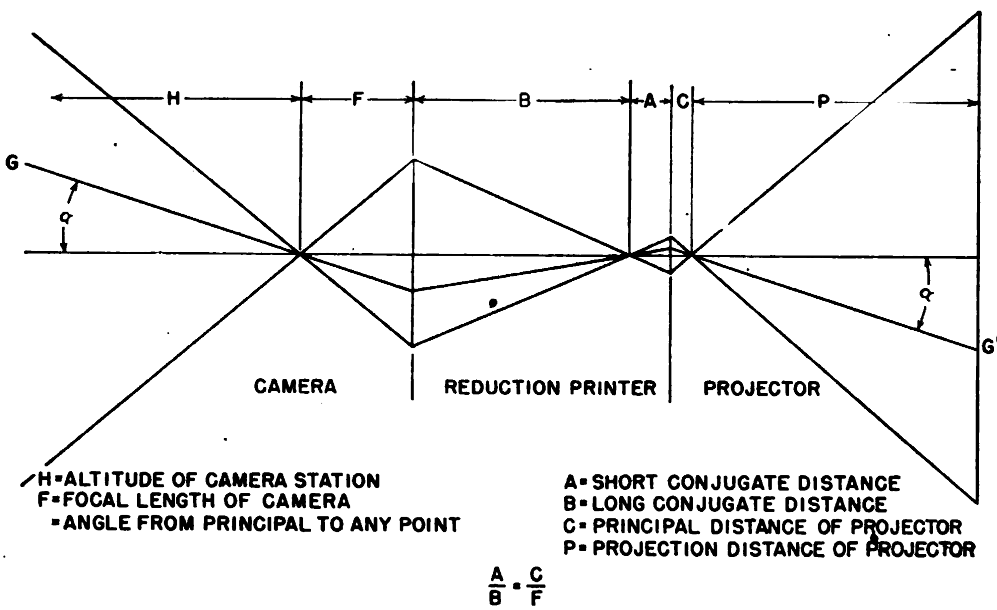

Figure 56. Camera, printer, and projector relationship.

nificance in this process is the fact that the ratio of the focal length of the camera lens to the principal distance of the Multiplex projector is proportional to the ratio of the original and reduced sizes of the photograph. The relationship between camera, printer, and projector is shown in figure 56.

b. MULTIPLEX REDUCTION PRINTER. The distances A and B in figure 56 are the conjugate

Figure 57. Multiplex reduction printer.

distances of the reduction-printer lens, and their ratio is the reduction ratio. The reduction printer, pictured in figure 57, has provision for changing this ratio by changing the conjugate distances. This is necessary to compensate for the varying focal lengths of the 6-inch Metrogon lens, which may vary from 151.0 to 155.0 millimeters. The principal distances of the projectors are constant within a small tolerance and are so assumed in using the reduction printer. The reduced photograph is recorded on a glass plate called a "diapositive," since it is a positive image on a transparent medium. Since the diapositive represents all the precision and high standards required in the photography, the reduction printer must be of high standard, optically as well as mechanically, so that the diapositive will be an exact reproduction of the negative. However, since the 6-inch Metrogon lens has considerable distortion present in it, compensating distortion must be introduced into the lens of the wide-angle reduction printer so that the diapositive will be free from distortion.

c. MULTIPLEX PROJECTOR. The Multiplex projectors are the means by which the diapositives are projected to form the stereoscopic model. Optics of the projectors are carefully selected so that the projection will reconstitute in miniature the cone of rays originally reflected from the surface of the earth when the aerial negative was exposed. The projectors can be translated on and rotated about their three axes so they may be oriented to each other to recover the true miniature spatial model. This is done by manipulation screws apparent in figure 54.

93. Plotting Scale, Flight Altitude, and Photograph Scale

The scale of the original negative is the ratio between the focal length of the aerial camera and the flight altitude. Since the reduction ratio is the camera focal length-projector principal distance ratio, the Multiplex plotting scale is the direct ratio between the projection distance of the projector and the flight altitude or $\frac{P}{H}$ figure 56. The best projection distance P of the Multiplex projectors is approximately 360 millimeters. If the flight altitude H is 20,000 feet, the plotting scale would be approximately 1:17,000. The plotting scale may also be expressed as the photograph scale times the ratio of the Multiplex projection distance P to the camera focal length F. In the T–5, or K–17 camera where the focal length is 6 inches, the ratio $\frac{P}{F}$ equals 2.4 for the most favorable projection distance. Thus with a 20, 000-foot flight altitude, the photograph scale would be 1:40,000 and the Multiplex plotting scale would be 1:40,000 x 2.4 or approximately 1:17,000. The table in appendix III gives these relations and other useful data for cameras having the 6-inch wide-angle lens.

94. Planning a Multiplex Mapping Project

a. GENERAL. The planning of each mapping project is an individual undertaking and must be planned according to the purpose required of the map and the time allotted for its completion. Shapes and sizes of areas, types of terrain, scale of plotting and publication, and amount and placement of control, all influence the planning.

b. PLOTTING SCALE AND CONTOUR INTERVAL. Plotting scale and contour interval depend upon the purpose for which the map is to be used. For battle maps, a publication scale from 1:20,000 to 1:31,680 is desired, and thus a plotting scale equal to or greater than the publication scale is required. The contour interval is usually 20 to 25 feet. For tactical maps, scales from 1:50,000 to 1:126,720 ordinarily are employed, with contour intervals from 5 to 100 feet depending upon the relief of the terrain. Such maps are prepared at larger Multiplex plotting scales and reduced for publication. Because of the characteristics of Multiplex equipment the contour interval normally fixes the flight altitude, which in turn determines the Multiplex plotting scale. However, there may be special cases where this is not true.

c. CONTOUR INTERVAL AND FLIGHT ALTITUDE. In planning a Multiplex mapping project the optical characteristics of the Multiplex equipment determine the flight altitude which will permit the plotting of contours at a particularly desired interval within the limits of specified accuracy. With proper ground control, the contour interval should generally be between 1/500 and 1/1,000 of the flight altitude, depending on the terrain being mapped. For average conditions the flight altitude should not be more than 750 times the contour interval desired. If all the terrain is rugged, the altitude then may be as much as 850 or 900 times the interval. Where the terrain is relatively flat, or lacks contrast that will register photographically, the flight altitude should be only about 600 times the contour interval.

d. PLANNING PHOTOGRAPHY. After selecting the contour interval and the scale at which the map is to be plotted, it is necessary to prepare specifications for executing the aerial photography. These specifications are prepared in accordance with section II. The flight altitude and the type of aerial camera to be used are determined by the characteristics of the Multiplex equipment. The table in appendix III gives the flight altitude for various plotting scales and contour intervals.

e. PLANNING CONTROL. (1) After the photographic requirements are determined, the planning of the mapping project must wait upon completion of the aerial photography. When the photographic index has been prepared, the boundaries of the area to be mapped should be plotted on it. This index will then readily show the photographs for which it will be necessary to establish control, and will serve as the basis for planning the entire control network.

(2) Most important to the planning of control in the field is the simultaneous performance of the various field operations so that the field data submitted to the Multiplex units will be complete. For example, if a set of photographs which contain only a part of the total data needed to map an area properly is submitted for Multiplex use, much efficiency is lost in attempting to commence Multiplex operations with incomplete information. Maximum efficiency requires that all photography bearing horizontal control points, vertical control points, and classification data; notebooks containing necessary descriptions and other data; bench mark data; and all other pertinent data, be submitted to the photomapping organization at one time. Then, only one setting of each model is necessary for all available data to be used in orientation and in compiling the manuscript.

(3) Further to promote efficiency of the entire mapping project, the field work should be led by men experienced in Multiplex operation. Many problems arise in the field which are readily solvable by men familiar with the use of the field data in the Multiplex, whereas men unfamiliar with its office use are at a loss as to the proper procedure. As far as possible, all men performing the field work for Multiplex should be given some training in Multiplex operation. If this is not convenient, every effort should be made to afford such training to the party chiefs.

f. MASTER INDEX. (1) The photographic index used in planning the Multiplex operations after the field work is completed becomes the master upon which the entire planning of the Multiplex plotting and plotting preparation is based. When the photographs are returned from the field with the control points identified on them, the horizontal control points are indexed or plotted on the photographic index in their correct locations. The computed positions—latitudes and longitudes—of these points are obtained and from them the meridians and parallels are plotted on the index by

interpolation between these control points. This establishes the position of each photograph with respect to the meridians and parallels. If the area to be mapped is limited by a specific meridian or parallel, the exact portions of the photographs to be worked can be determined readily.

(2) If definite Multiplex plotting sheets are to be used, these outlines as well as the outline of the publication sheets should be indicated on the index. A composite picture then exists from which an accurate relationship between photographs, control, and sheet lay-out is evident. A convenient method of plotting each of the various items on the index is to plot each in a different color. Usually the horizontal control points are plotted in red, the meridians and parallels in yellow, the plotting sheets in blue, and the publication sheets in heavy yellow, since these are usually bounded by meridians and parallels.

95. Preparation of Data

a. General. Preparations for initiating the Multiplex bridging and plotting are begun immediately upon receipt of the aerial film. However, only limited preparation can be accomplished at this time, since most of the preparatory work depends upon the return of the photographs from the field, and the field parties have just received them. Therefore, the preparation at this time is confined mainly to diapositives. Other preparations which can be made now are constructing the projection, laying out the acetate sheeting to be used for Multiplex bridging so that it will lie flat, and preparing the individual compilation sheets, if these are to be used. When the control data are received, a rapid routine of preparation is immediately begun. First the master index is prepared. Following this, the horizontal control points are plotted on the projection. At the same time photographs are prepared for use in Multiplex plotting, and the control data are assembled from field notes. During this preparation, the procedure to be followed is planned from the master index.

b. Preparation of Diapositives. The diapositives represent the photography with all its high precision. Preparation with the utmost care is required. This necessitates ample time. Exposure and development must be timed accurately, and each negative must be treated independently so that proper quality can be achieved in each diapositive. The images on each diapositive must be uniformly clear and have good contrast so that the resulting stereoscopic models will be clearly visible and therefore easily measured.

c. Sheet Lay-outs. Inspection of the master index will show the lengths of the bridges required and the order in which the bridges should be made. The acetate sheeting to be used for the bridging of a strip should be laid over the projection and the control for that strip pricked through and marked so as to be readily identifiable. These sheets are then ready for the Multiplex operators who are to perform the bridging. At the completion of the bridging and its adjustment to adjacent strips, the minor control established by the Multiplex must be transferred to the Multiplex plotting sheets. This may be done by transferring the minor control points to the projection base during the adjustment of adjacent strips to each other, and then transferring this control to the individual compilation sheets upon which the plotting will be performed. If not much adjustment is required between strips, it may be done by transferring the minor control points directly from the bridging sheet to the compilation sheet. The compilation sheet may be laid out either as a standard-size sheet, bounded by grid lines or meridians and parallels, on a flexible base suitable for Multiplex compilation; or as a piece of tracing paper upon which control sufficient for only one model is transferred. The first method is preferred, as it leads to greater accuracy.

d. Transferring Control Points and Preparing Control Data. To facilitate Multiplex operations, control identifications must be transferred from picture to picture and from strip to strip so that all control is properly marked and identified on the photographs. Usually the identifications of the horizontal control points are pin-pricked on all odd- or even-numbered photographs and a red triangle inked around each, while the vertical control points are pin-pricked on the alternate photographs and a black circle inked around each, as shown in figure 6. From information in the notebooks, tabulations of the data for all points can be made and reproduced, so that each operator is supplied with all necessary control descriptions.

96. Organization of Bridging and Plotting Operations

a. General. During the preparation of the Multiplex data the bridging and plotting operations are planned. The organization of neither

the bridging nor the plotting can be standardized, since this depends upon the size of the project, the nature of the terrain to be mapped, the amount and placement of control, the availability of all necessary data from the field, and a number of unforeseen factors.

b. Shift Operations. To produce a map in the minimum of time two or three shifts are usually employed in the bridging and plotting operations. Therefore, each Multiplex unit is operated by a two- or three-man team. Men must be teamed by temperament and style of plotting, since the efficiency of each unit depends largely upon these factors.

c. Bridging. Since the normal density of control used for Multiplex mapping is the minimum which can be used to produce a map of desired accuracy, it is necessary to bridge between bands of control by means of Multiplex triangulation. Only operators of great experience are used for this work, because the accuracy of the whole map depends upon the accuracy with which the bridging is accomplished. A sufficient number of Multiplex rooms and Multiplex projectors are designated for this purpose. Adjacent strips are triangulated simultaneously in different rooms so that, upon completion of triangulation and adjustment, a portion of the area will be available for plotting. The order for bridging strips should be planned so as to release areas for plotting at the quickest opportunity. In this way, the publication of the first portion of the completed map will be expedited.

d. Plotting. In assigning plotting sheets to the various Multiplex units, it is best to assign to each unit as large an area as possible. This will depend upon the progress of the triangulation in relation to the plotting. If a large area is assigned to one unit the problem of joining the compilation of two adjacent strips is not difficult, and familiarity with the control, planimetric features, and topographic characteristics of the area helps to speed the work. When the area to be mapped is small, or the Multiplex triangulation data are delivered a little at a time, it is necessary to assign the work by tiers of compilation sheets and sometimes by individual strips of photographs. In this case, it is important that the work be planned so that adjacent models will not be plotted simultaneously by two units, lest the overlapping area between strips be plotted twice. A schedule of assignment for each unit should be planned well in advance, and posted, so that all operators can determine where adjacent areas are being worked, as well as their own assignments. This schedule should be broken down into detailed assignments which should show the strip number, limiting model numbers between control, and the plotting-sheet numbers.

97. Multiplex Triangulation

a. Purpose. (1) The purpose of Multiplex triangulation is similar to that of radial-line triangulation—to establish the true positions of series of image points between bands of ground control in order to create a system of control points which will insure the position accuracy of all topographic features plotted within them. In the Multiplex system, horizontal and vertical bridging are done simultaneously, whereas radial-line triangulation is horizontal bridging alone.

(2) Horizontal bridging by Multiplex is benefited by the use of vertical control, since tips and tilts in any or all photographs are removed and therefore errors from that cause are eliminated. Due to the advantage gained by stereoscopic plotting, as discussed in paragraph 89*c* (1), the purpose of Multiplex triangulation also differs somewhat from that of radial line since it is not necessary in the Multiplex system to establish the positions of auxiliary points, no matter what the amount of relief. Theoretically, due to the advantage of restitution by stereoscopic projection, the true positions of the photograph centers, or image points near these centers, are sufficient to insure accurate positions of all features plotted from the model between them. Practically, however, points are also obtained in the sidelap between adjacent strips.

b. Method. The method of accomplishing Multiplex triangulation is similar to that of radial line, in that the first Multiplex model is oriented to control, thereby establishing its true scale; a second model is added, based on the scale of the first, and succeeding models are extended in this manner until further control is reached. In this system the second and succeeding models are tied to each other by a vertical "pass point" which is chosen near the principal point of the forward photographic image and which, as in the radial-line system, appears in the triple overlap area. This vertical pass point controls the spacing between the second and third projectors which determines the scale of the model, as illustrated in figure 58. The identical scales between the first and second models are indicated by the fact that the elevation of

the pass point is the same in both models after absolute orientation.

c. **Procedure.** To accomplish triangulation, it is first necessary to set up the first Multiplex model in absolute orientation. Absolute orientation is achieved when the model is definitely scaled and horizontalized to control or, in other terms, when the model is an exact miniature of the corresponding ground surface so that measurements made on this model will be true. To make an absolute orientation it is necessary first to orient the two projections relatively, a process which creates the stereoscopic model; and second, to scale and *horizontalize* that model to horizontal and vertical control.

(1) *Relative orientation.* Relative orientation is the adjustment of the cone of rays from the projection of one diapositive to intersect corresponding rays in the projection from the second diapositive. The orientation of the model is not in its true relationship to the sea-level datum; but, since the two projections are in true relationship to each other, a stereoscopic model is created. The orientation is actually accomplished by a process in which parallaxes are removed until the third dimension appears. The creation of the model depends mainly on the removal of vertical or "Y" parallax, since this is equivalent to forming the ray intersections in space. Horizontal or "X" parallax is removed by varying the height of the tracing-table platen. Horizontal parallax is equivalent to the differential parallax measured in mapping with the stereocomparagraph.

(2) *Scaling and horizontalizing the model.* The stereoscopic model created by relative orientation is scaled to at least two horizontal control points by a trial and error setting of distance between projectors. When the model is correctly scaled, the control point images on the model can be registered in coincidence with the corresponding points plotted on the base sheet. This process is illustrated in figure 58. The model is horizontalized by tipping and tilting it so that the elevations derived from vertical scale readings when the floating point is brought to rest on vertical control points in the model are equivalent to the true ground elevations. At least three vertical control points, properly positioned, are required to make the datum plane of the model true with respect to the sea-level datum.

(3) *Completing triangulation.* When the first model is in absolute orientation the orientation of the second model is simply the relative orientation of the projection of the third projector to that of the second projector. The model thus created is theoretically true, since the datum of the second model is related to a true datum plane. As in *b* above, the second model is scaled by the pass point system illustrated in figure 58. In the same manner, a series of models is set up until further control is reached. The entire setting is scaled be-

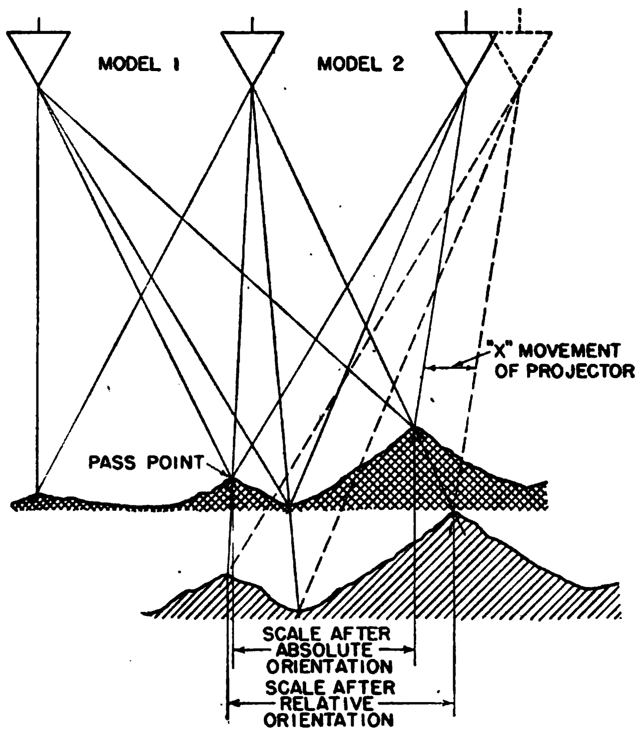

Figure 58. Scaling the Multiplex model.

tween bands of horizontal control by expanding or contracting the distances between projectors until the images of control points in the stereoscopic model are correctly registered with the control points plotted upon the base sheet. Then the pass points required to make the tie between adjacent models and adjacent strips are plotted in their true positions upon the base sheet.

The pass points are used as minor control points in the plotting operation, and must be located in position as well as in elevation. The elevations of the pass points are determined by an analytical adjustment between vertical ground control points, as described in TM 5–244. This is necessary because of the inherent curvature of the datum which is present in any bridge or extension with wide-angle Multiplex equipment. Adjacent strips must be adjusted to each other by determining mean positions and elevations of common pass points.

If an extension must be made with control only at the starting end, the result is a cantilever extension which must be adjusted to adjacent strips without the benefit of additional control. After an entire area has been triangulated and adjusted, the minor control points for a small area may be traced on another sheet—the plotting sheet—for distribution to various Multiplex plotting units.

98. Manuscript Plotting

a. GENERAL. The Multiplex plotting process is divided into two general phases: setting and orienting the models, and plotting the manuscript from them. The first phase was discussed in paragraph 97; this paragraph will deal with the second.

b. PROCEDURE. Before commencing the plotting operation, the operator must obtain the necessary plotting sheet, photographs, diapositives, and control data. The plotting sheet is placed on the Multiplex table under the projectors, which are oriented to the control plotted thereon—previously established by Multiplex triangulation. While the model is in correct adjustment, it is best to plot the contours first. These are traced successively throughout the model by locking the tracing-table platen at the desired contour elevation and maintaining the floating mark constantly in contact with the ground. Following the contours, the planimetry is plotted by maintaining the floating mark in contact with the ground while the feature is being traced. When plotting areas adjacent to those already drawn, detail along the edges of the model already compiled is transferred as a match line, and is joined during the plotting of the new model. Since Multiplex plotting is done in pencil, the Multiplex operator makes no attempt to produce a finished, drafted map. As long as the symbols are readable and complete, he is considered to have performed his work properly.

99. Checking and Editing

Upon completion of the manuscript, the plotting should be checked. Those employed on this step should work under close coordination to insure uniformity. The checking and editing process is generally as follows: checking the plotting for thoroughness; checking the consistency of the topography with spot elevations and all orders of vertical control; checking the consistency between the shapes of the ground and the shapes expressed by the contours; classifying roads; and adding name data, boundary lines and any supplementary information available from other sources. The second item is best accomplished by using the photographs and a magnifying stereoscope. Minor corrections or additions may be made by the checker, using the photographs as a guide. Any major errors or omissions noted should be corrected by the operators resetting the model involved. Field checks should be made, if possible.

100. Drafting and Reproduction

a. For preparation of a drafting base, a combination of plotting sheets may be assembled and the desired publication-sheet area photographed from them. The photography must be accomplished with a precise copy camera. A blue-line positive image then may be printed on a stable base for drafting. Following the inking on the blue-line copy, the lettering may be applied by hand or "stick-up." The woods may be shown by means of Zipatone, which is best stuck on a sheet of acetate film base registered over the sheet for copying; or Zipatone may be applied directly to the sheet as a last drafting step.

b. After drafting, lettering, and placing of woods the final sheet may then be copied to the desired publication scale by the precision camera, and a negative obtained for making prints in quantity. When multicolored, lithographic reproductions are to be made it is necessary to perform color-separation drafting. In this case, the original negative prepared from the Multiplex manuscript may be used to prepare as many identical blue-line prints as there are to be colors on the final reproduction. Color-separation sheets also may be prepared in the Multiplex plotting by using acetate as the compilation sheets, registering the sheet on base control under the Multiplex, and plotting only the data which belongs on the respective color-separation sheets.

101. Accuracy

Factors affecting the accuracy of the completed map include the character of the terrain, control, and photography, as well as the ability of the operator. The Multiplex is the most precise method of mapping from aerial photographs used in the War Department; however the mechanical and optical features of the equipment limit the accuracies which can be attained. A detailed discussion of all the factors which affect Multiplex accuracy is contained in TM 5–244, and in order

properly to estimate the probable accuracy of a resultant map produced by the Multiplex, all of these factors must be considered. However, it may be stated that by proper application of the Multiplex procedure, a map having the standard accuracies of a civil map can be produced. The most stringent requirement for military maps is the accuracy required for unobserved artillery fire, which is 33 yards horizontally and 25 feet vertically. This requirement can likewise be met by proper application of the Multiplex procedure. Where it is necessary to extend control into enemy territory by cantilever extension, the accuracy of the final map can obviously be no better than this extended control. Tests with five parallel strips of photography at an altitude of 23,500 feet, in which control has been extended about 40 miles, have indicated that this extended control will give a map which will locally, within the normal ranges of artillery, meet the accuracy requirements for artillery fire, although that local area of the map may be displaced slightly from the true geographic position and datum.

SECTION XI

SPECIAL MAPPING METHODS

102. Optical Rectification

a. GENERAL. (1) Optical rectification is a process of projecting the image of a tilted aerial negative into a horizontal plane. A photographic print made by such a projection contains all the geometrical qualities of a vertical photograph taken at the same position in space. To accomplish this correctly, certain mathematical relationships are maintained between the negative plane, the lens, and the easel, in the rectifying camera. Properly designed rectifiers for this purpose are of two main types: those in which the optical axis of the rectifier lens is the common reference or base direction of the instrument, and those in which the line between the principal point of the negative and the rectifier lens is the common reference of base direction.

(2) Figure 59 illustrates schematically a rectifying camera of the first type. Such a rectifier has provision for rotating the negative and easel planes about parallel axes which are perpendicular to and intersect the optical axis of the lens; for varying the distances between the negative, lens, and easel: for shifting the negative in its own plane in a direction perpendicular to the axis of rotation; and for rotating the negative through 360° in its own plane so that the principal plane of the photograph can be placed perpendicular to the axes of rotation of the negative and easel.

(3) Figure 60 illustrates schematically a rectifier of the second type. This type rectifier has provision for rotating the negative, lens, and easel about parallel axes which are in the same plane; for varying the distance between the negative, lens, and easel; for rotating the negative through 360° so that the principal plane of the photograph can be placed perpendicular to the axes of rotation of the negative, lens, and easel.

b. COMPUTATIONS FOR RECTIFICATION. The equations for computing the various distances and angles shown in figure 59 for rectifiers of the first type are as follows:

$$\sin {}'p = \frac{f}{F} \sin T$$

$$\sin {}'n = \frac{f}{MF} \sin T$$

$$y = \frac{f \cot {}'p}{\cos {}'n} - F \cot T$$

$$a = f\,(1 + \cot {}'p \tan {}'n)$$

$$b = a \cot {}'n \tan {}'p$$

In which F = focal length of camera lens
f = focal length of rectifier lens
T = Tilt of aerial photograph
M = Magnification ratio

The equations for computing the various distances and angles shown in figure 60 for rectifiers of the second type are as follows:

$$\sin {}'p = \frac{f}{F} \sin T$$

$$\sin {}'n = \frac{f}{MF} \sin T$$

$$\alpha - \beta = {}'p + {}'n$$

$$\cot \frac{(\alpha+\beta)}{2} = \tan \frac{{}^2T}{2}$$

$$\tan \frac{(\alpha-\beta)}{2}$$

$$\gamma = \beta + {}'p$$

$$c = f \operatorname{cosec}^2 \lambda \operatorname{cosec} \gamma$$

$$d = f \sec^2 \lambda \operatorname{cosec} \gamma$$

where $\tan^2 \lambda = M \sec T$
M, F, f, and T are the same as above.

103. Approximate Rectification

Approximate rectifications of aerial photographs with small tilts are sometimes made with an ordinary enlarger having a tilting easel. In such instruments the sharpness of the image depends on the depth of field of the lens, and the rectified print is not necessarily a true perspective projection on a horizontal plane. Sometimes provision is made in enlargers having tilting easels for canting the lens. This will improve the focus in the projection, but the projection is still not neces-

sarily a true rectification. Approximate rectifications may be used to advantage in mosaic work, but for accurate radial-line plotting or other photogrammetrical uses they are unsatisfactory.

104. Rectifying Attachment for Copy Cameras

The rectifying attachment for the copy camera is designed as a field expedient to rectify photographs with small tilts. With the attachment a contact print of the tilted aerial negative is copied, producing a rectified negative from which contact prints may be made for use in laying mosaics. This attachment consists of a copy holder (fig. 61) which is clamped on the easel of the copy camera, and a negative holder (fig. 62) which fits into the circular half-tone screen housing. The formulas given in paragraph 102*b* for rectifiers, in which the optical axis is the base direction, are used for computing the angular settings of the easel and negative. In this instance the negative plane of the equivalent rectifier becomes the plane of the contact print to be copied, and the positive plane the plane of the rectified negative. The attachment generally is used at 1:1 magnification only, and it will be noted from the formula that for this condition $t_p = t_n$, $y = F \tan T/2$ and $a = b = 2f$. Rectifications made with this attachment are theoretically correct.

105. Use of Rectifiers

The most rapid method of setting a rectifier is from computed values for the various motions. It is necessary to know the amount of tilt and its direction in the aerial photograph, the focal lengths of the aerial camera and of the rectifier lens, and the magnification ratio. These computations may be facilitated by the use of nomograms or charts where quantities of rectified prints at various tilts and magnifications are to be made. Sometimes, the settings of the rectifier are made by trial. It is necessary that the horizontal positions of four points which can be identified in the photograph be known, and that these positions be corrected for displacement due to relief. This method is best

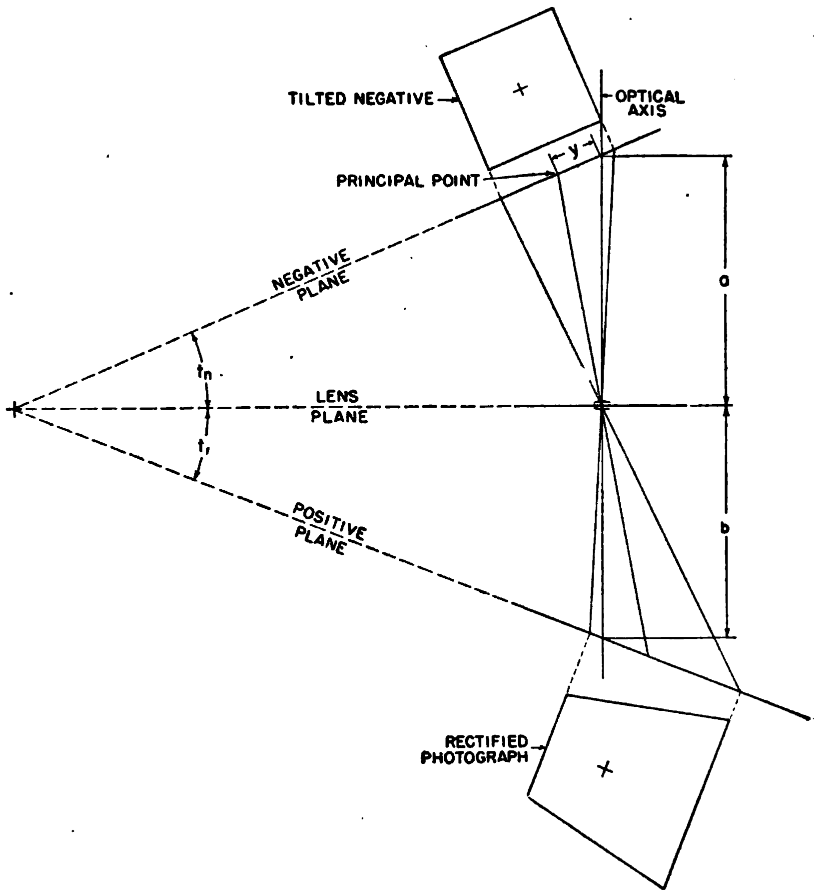

Figure 59. Schematic diagram of rectifier in which optical axis is base direction.

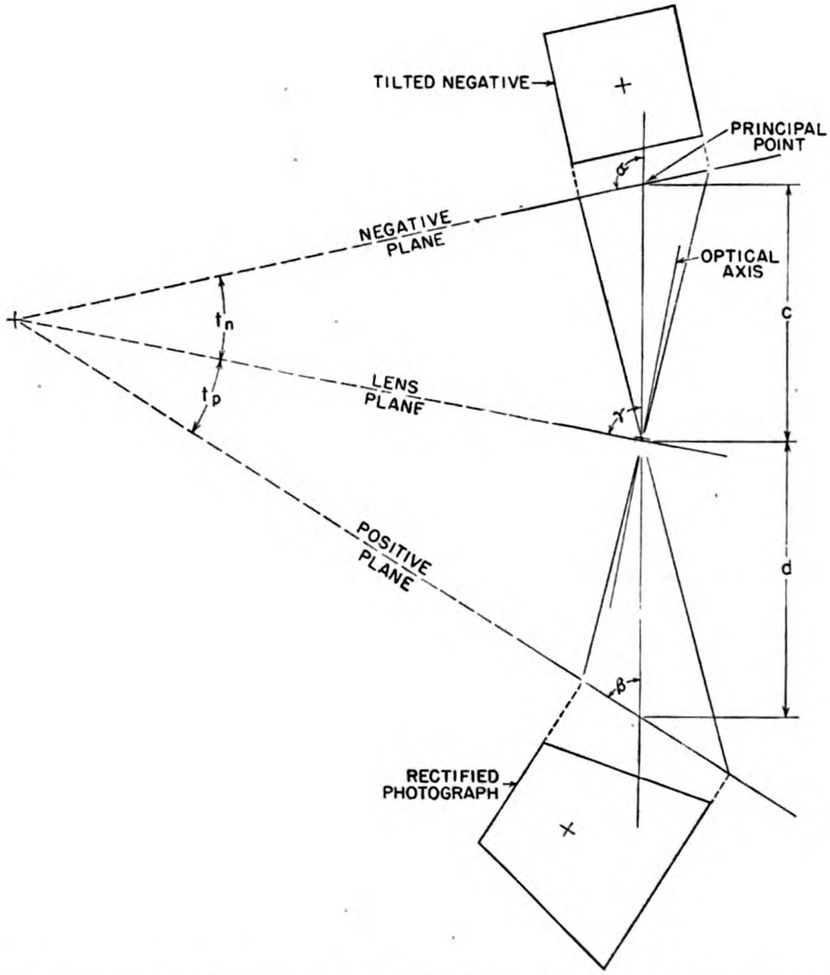

Figure 60. Schematic diagram of rectifier in which line joining principal point of negative and rectifier lens is base direction.

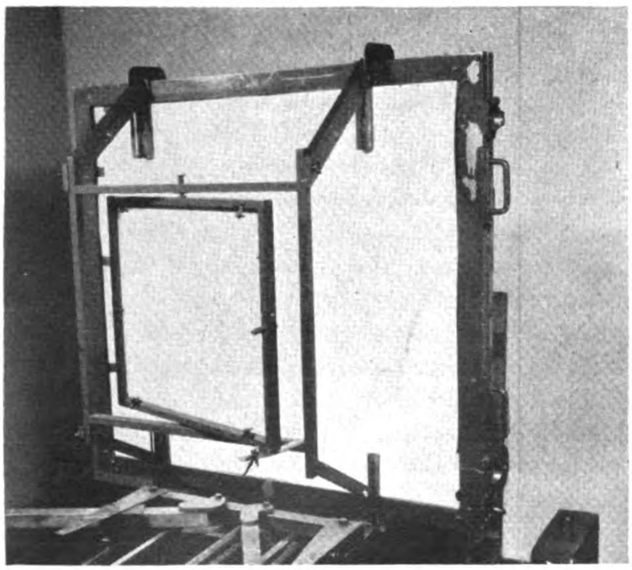

Figure 61. Rectifying attachment for copy camera—copy holder.

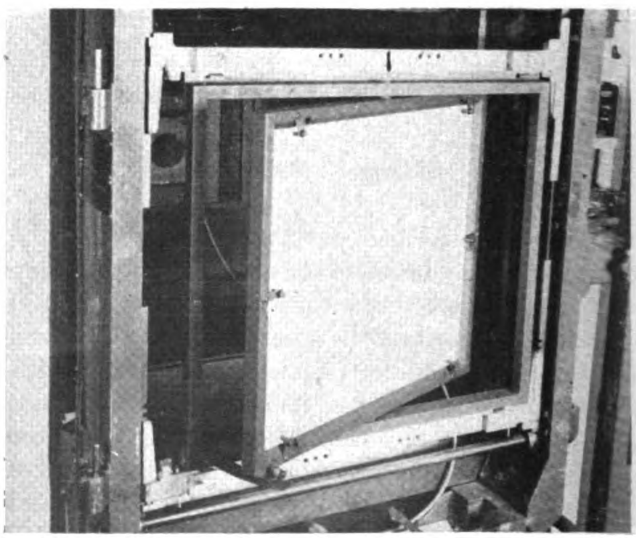

Figure 62. Rectifying attachment for copy camera—negative holder.

suited to automatic rectifiers, that is, those in which the tilting and spacing of the planes of the negative, lens, and easel are interconnected so that the projection is in focus at all times.

106. Perspective Grid

a. General. The perspective grid is a grid placed on a tilted photograph which represents a square grid on the ground. Its use is primarily suited to high-oblique photography of terrain of low relief where it is desired to sketch planimetric features in their relative map positions. In use, the detail on the photograph is transferred square by square to the grid on the plot. Where a large number of oblique photographs of similar tilts and altitudes are to be plotted by this method it is advisable to plot families of grids on some transparent medium, to be used as overlays in the plotting operation.

b. Construction. The construction of a perspective grid is illustrated in figure 63. It is necessary to know the focal length of the camera, the flight altitude, the tilt, and the location of the trace of the principal plane in the photograph. In the figure, the distance HP equals $f \tan \theta$, where f is the focal length of the camera lens in inches

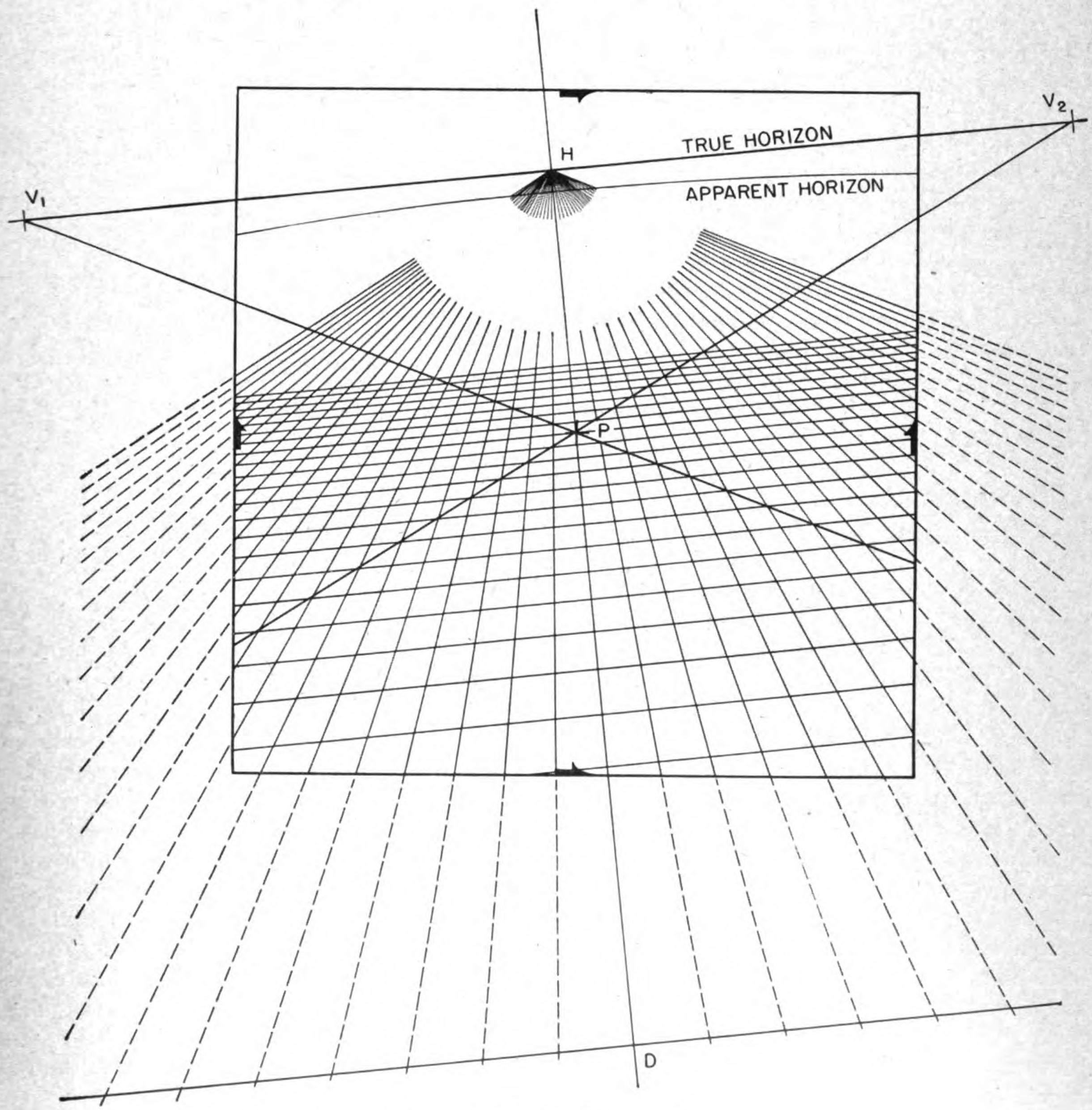

Figure 63. Perspective grid.

and θ is the tilt of the photograph below the horizon. This distance is laid off along the trace of the principal plane. The true horizon line is then constructed perpendicular to HP. All lines parallel on the ground then will vanish in this line. Lines parallel to the trace of HP on the ground will vanish at H, and parallel lines at a 45° angle to the projection of HP on the ground will vanish at V_1 and V_2. The distances $HV_1 = HV_2 = f$ sec. θ. The distance HD to a point D, where one unit or one inch on the plane of the photograph will be equivalent to the grid spacing on the ground, equals $\frac{H}{G \cos \theta}$ where G is the grid spacing on the ground and H is the flight altitude. Lay off this distance and construct a perpendicular to HD at D. Lay off 1-inch divisions on this line, and connect them with point H. These lines then represent parallel lines at the grid spacing. Lay off the distances f sec. θ along the true horizon from H, locating V_1 and V_2 and draw the lines from V_1 and V_2 through P. The intersections of these lines with the two lines vanishing at H, which are equidistant each side of HD, then locate a grid line at right angles to HP. Similar intersections with other pairs of lines vanishing at H locate the series of parallel grid lines perpendicular to HP, this completing the grid.

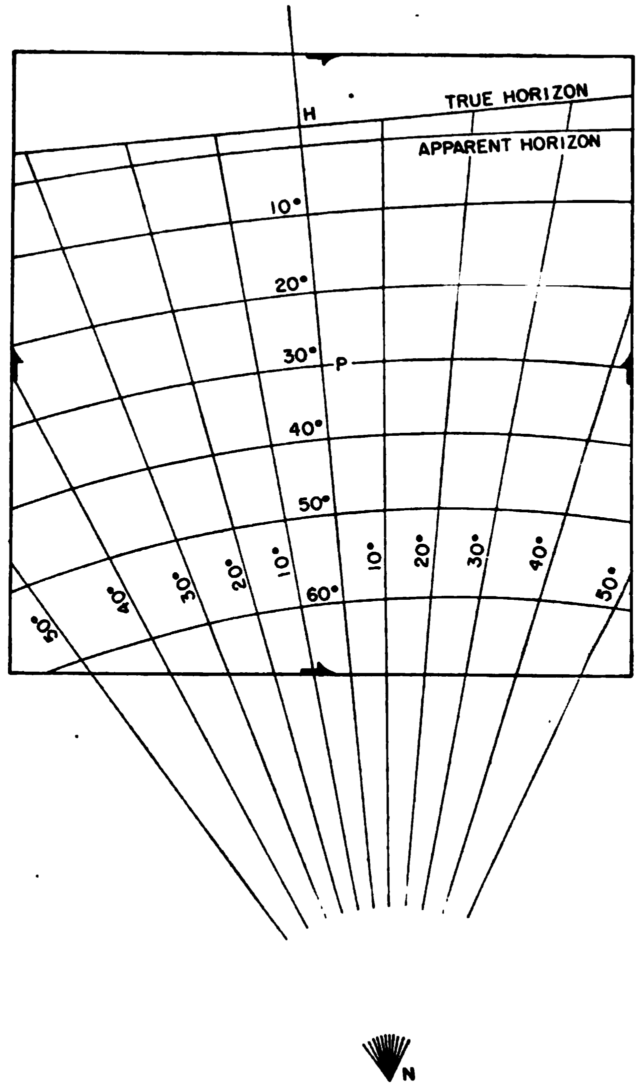

Figure 64. Azimuth grid.

107. Azimuth Grid

a. General. The azimuth grid on a photograph consists of a series of straight lines, radiating from the plumb point, which represent a definite angular interval on the ground, and a series of hyperbolic curves, which represent some definite interval in inclination below the horizon. The ground equivalent of this grid is a series of radiating lines at the angular interval chosen, and a series of concentric circles of varying radii, the radius of any circle being equal to the flight altitude multiplied by the cotangent of the depression angle. With the azimuth grid, the horizontal and vertical angles to any point may be interpolated on the photograph. As with the perspective grid, where a number of photographs of similar tilts are to be used, it is advisable to make up families of grids for various tilts to be used as overlays on the photograph.

b. Construction. The construction of the azimuth grid is illustrated in figure 64. It is necessary to know the tilt, the focal length, and the location of the trace of the principal plane on the photograph. The flight altitude need not be known to construct the azimuth grid. Lay off the distance $PH = f$ tan θ, where θ is the depression angle, and through H construct a perpendicular which is the true horizon. Along the true horizon from H lay off distances equal to f sec θ tan ϕ, where ϕ is the horizontal angle on the ground to be represented by an azimuth line on the photograph. Locate the point N, the plumb point, which is at a distance from P equal to f cot θ, and draw the lines from N to the points located on the horizon line. The location of the lines of equal depression may be located by plotting several points of equal depression angle across the photograph and connecting them with a smooth curve. The distance from the horizon on the trace of the

principal plane for a depression angle V is equal to $PH-f\tan(\theta-V)$. To locate other points on the lines of equal depression, erect perpendiculars to the horizon line at the points where the azimuth lines intersect the horizon line, and lay off along these lines from the horizon the distance y from the following formula:

$$y=\frac{f\tan V}{\cos^2\theta\,(\cos\phi+\tan V\tan\theta)}$$

using various values of V and ϕ, depending upon the point being computed.

108. Modified Azimuth Grid

a. GENERAL. The modified azimuth grid differs from the regular azimuth grid in that the depression angle lines are straight lines instead of hyperbolic curves. It is much easier to construct, and may be used quite conveniently in rough determinations of elevations from oblique photographs. (See par. 110.) With this grid, the projection of the vertical angle on the principal plane may be interpolated from the grid lines.

b. CONSTRUCTION. The azimuth lines of the modified azimuth grid are constructed as explained in paragraph 107 for the regular azimuth grid. The depression-angle lines are constructed perpendicular to the trace of the principal plane on the photograph, through the points located at distances of $PH-f\tan(\theta-V)$ from the horizon. The modified azimuth grid is illustrated in figure 65.

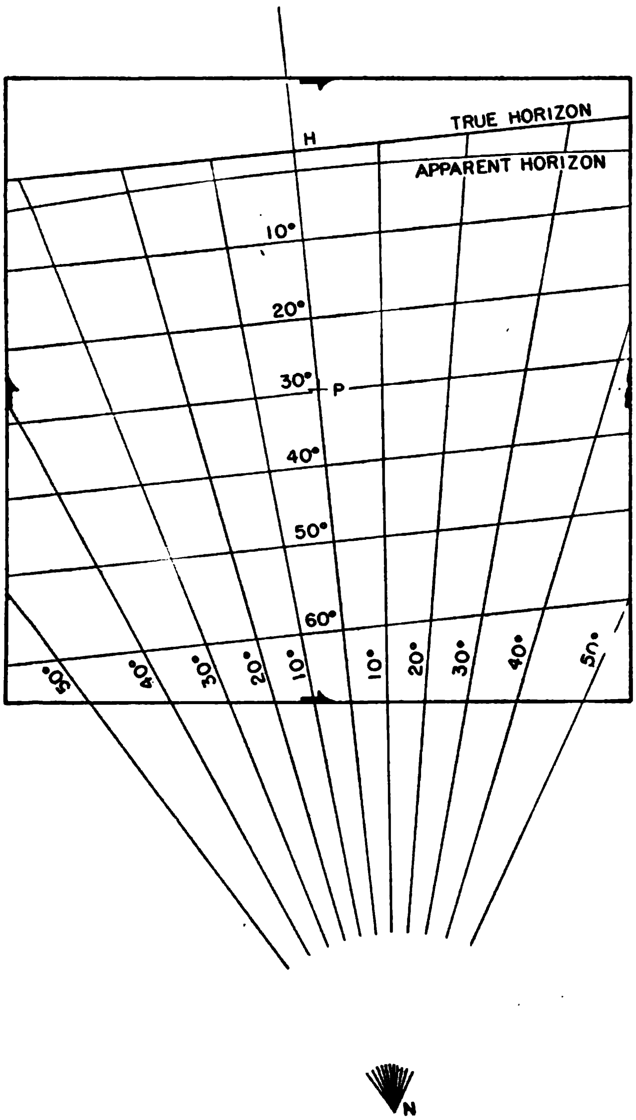

Figure 65. Modified azimuth grid.

109. Vertical Angles from Oblique Photographs

Knowing the tilt, the focal length, and the location of the trace of the principal plane in the oblique photograph, vertical angles at the exposure station from the horizontal plane through the exposure station to various points in the photograph may be determined by interpolation from a properly constructed azimuth grid; or, more precisely, by an analytical computation from coordinate measurements on the photograph. By measuring the distance PA and the angle S (fig. 23), the vertical angle V may be computed from the equation:

$$\sin V=\frac{f\sin\theta+PA\cos\theta\cos S}{\sqrt{f^2+PA^2}}$$

By measuring the rectangular coordinates of the point in question, using the true horizon line as the X axis and the trace of the principal plane as the Y axis, the vertical angle may be determined from the equation:

$$\tan V=\frac{fy\cos\phi}{C^2-dy}$$

In which $C=f/\cos\theta$

$d=f\tan\theta$

$$\tan\phi=\frac{CX}{C^2-dy}$$

X is positive to the right of the trace of the principal plane and Y is positive below the horizon.

110. Determination of Flight Altitude or Ground Elevation

a. METHOD. (1) With the vertical angle determined from the photograph, and the horizontal ground distance from the plumb point of the exposure station to the ground point, and the elevation of the ground point known, the flight altitude may be determined from the expression: $H=E+M\tan V$, in which H equals flight altitude,

E equals elevation of the ground point, and M equals horizontal distance. Conversely, with the flight altitude and the ground distance known, the elevation of the point on the ground may be determined. The above expression for H assumes a horizontal datum tangent to the surface of the earth directly beneath the exposure station, and no refraction of the light rays by the atmosphere in forming the photographic image.

(2) A correction for curvature and refraction may readily be applied to the above, as indicated in figure 66. The correction for curvature and refraction is indicated as KM^2, in which K is the coefficient of curvature and refraction. For all practical purposes this coefficient may be taken as equal to 0.574 when M is expressed in miles. The projection on the principal plane of the vertical angle to any point may be computed from measurements on the photograph, or may be interpolated from the modified azimuth grid and used to compute elevations. When this angle is used, the value M in the expression $H=E+M \tan V$ is the ground distance projected to the ground trace of the principal plane.

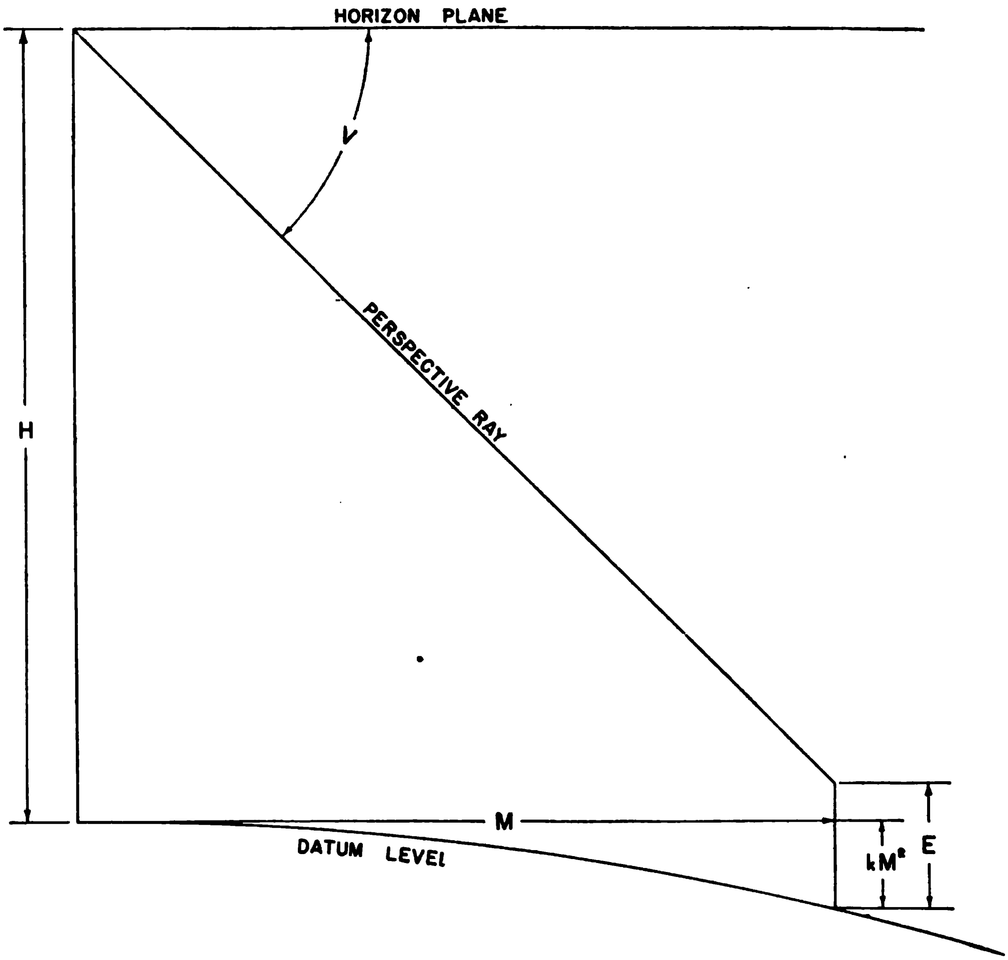

Figure 66. Determination of elevations from oblique photographs.

b. Accuracy. The accuracy with which elevations may be determined from oblique photographs depends upon the accuracy with which the flight altitude, vertical angle, and ground distance may be determined. In the more usual type of oblique photography, where there is little ground control, the flight altitude is accepted as that reported by the photographic crew, and the horizontal ground distance is determined from some type of radial-line plot. The accuracy with which the vertical angle is determined depends upon the accuracy with which the coordinates of the point are measured on the photograph. The elevation thus determined is not usually reliable. Where sufficient ground control is available and properly placed in the area covered by the oblique photograph, it is

possible to make adjustments analytically to improve the accuracy of elevation determination. However, those instances in which such ground control is available are so rare, and the computations necessary are so involved, that such procedure is not of much practical value.

111. Paper-strip Method

The paper-strip or four-point method of restituting a tilted aerial photograph to a horizontal plane can be used satisfactorily with photography of any tilt where the relief is not great. The method is explained in paragraph 97, TM 5–230. Its chief application is with low obliques or near verticals, and it is especially useful in map revision. Knowledge of the focal length, flight altitude, or tilt is not necessary, but the location of four points in the area covered by the photograph must be known. This method also may be used to extend control through short distances. With four points known in position in one photograph, the position of all four points common to an overlapping photograph may be established, and thus the control net expanded. The construction results in a network of triangles on both the photograph and the plot, from which detail may be transferred.

112. Map Revision

a. Aerial photography is advantageously used in map revision. The method to be used in any particular instance will depend upon the quality of the original map to be revised and the particular type and quantity of information to be added. In many instances the original map is of such poor quality that it is more economical to redraw the map completely by photogrammetrical methods.

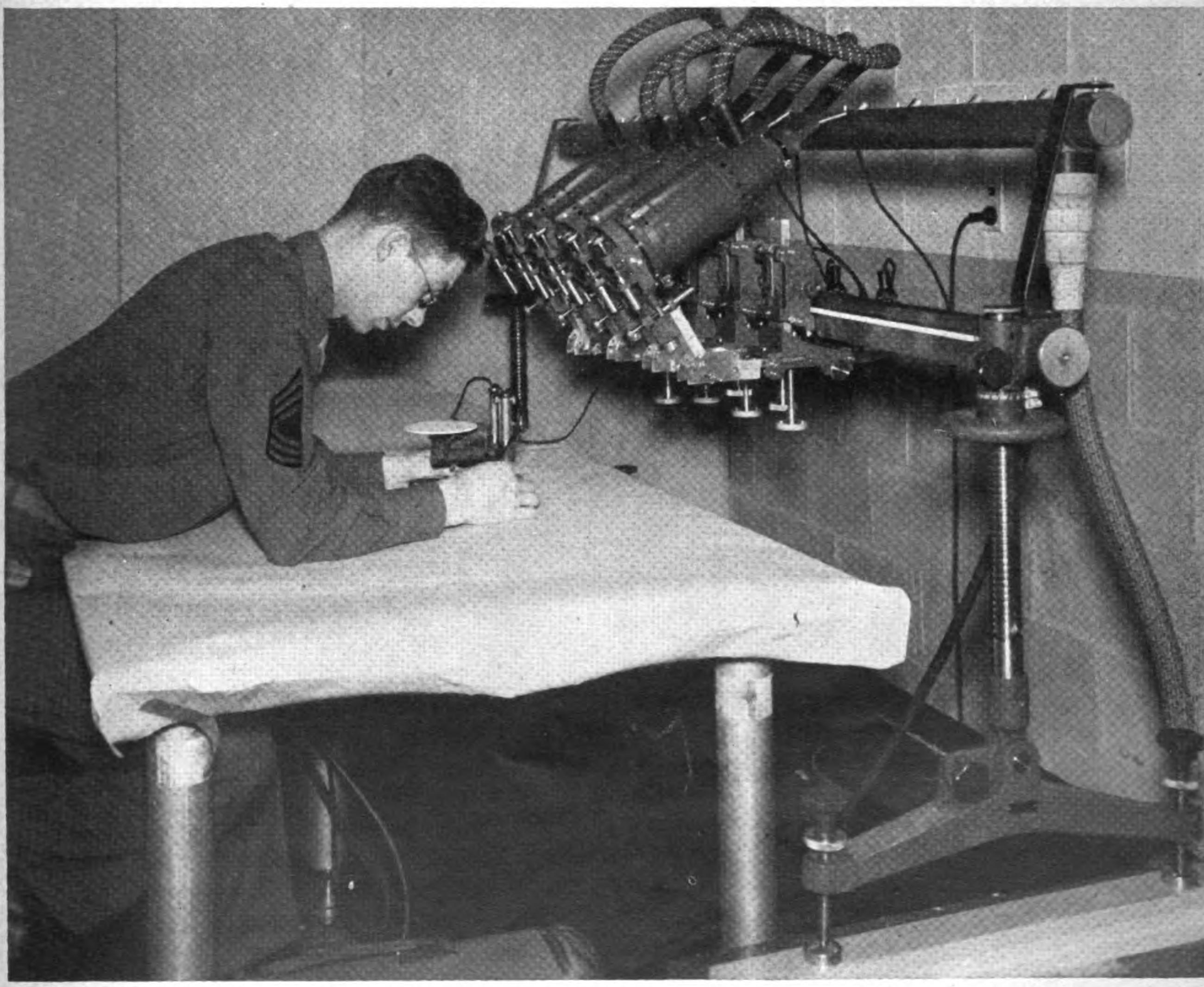

Figure 67. Wide angle Multiplex equipment adapted to plotting from oblique photography.

In other instances it may be necessary only to add new construction of buildings or roads in the area. In the latter case the locations of these objects may be determined by the radial-line method.

b. In some cases it may be necessary to run a radial extension of several photographs, using planimetric information which can be identified on both the map and the photograph as control. Detail is compiled between control points, as described in section VI. Where there is a sufficient density of identifiable detail which can be used as control, radial-line extension is not necessary and the plotting of planimetry is performed in the normal manner. Where the relief is not great and only a single photograph is available, the paper-strip method, or the grid-division method, either triangular or rectangular, may be used, as described in paragraph 97, TM 5–230.

113. Oblique Multiplex Mapping

The only practicable method of obtaining elevation data from Tri-Metrogon or other oblique 6-inch photography is with the Multiplex equipment. All computational or graphical methods have severe limitations both as to speed and accuracy. The Multiplex method is somewhat limited with respect to the focus of the projectors, but in most situations a reasonable inch-to-the-mile topographic map may be obtained. Oblique photography for use in the Multiplex equipment has application to mapping of island groups where vertical stereoscopic pairs will not bridge the gap between islands. All oblique mapping with the Multiplex projectors requires the use of special adapters to allow the projectors to be tilted over large ranges. Such methods have application only to base topographic units.

APPENDIX I

GLOSSARY

Aberration. A defect of an optical image caused by the fact that essentially no lens system can form a perfect image.

Absolute orientation. *See* Orientation.

Absolute parallax. *See* Parallax.

Aeronautical chart. A map especially designed for the aviator, showing obstructions, aids to navigation, and other information to assist the aviator in navigating.

Air base. The line joining two air stations. (*See* Air station; Camera station.)

Air station. The camera station for an aerial photograph.

Altimeter. An instrument which utilizes relative pressure of the atmosphere to indicate the vertical distance above a specified datum plane.

Altitude. Vertical distance above the datum, usually mean sea level, to an object or point in space.

Anaglyph. A picture printed or projected in complementary colors which combines the two images of a stereoscopic pair in such a manner that one image appears in one color and the other in a complementary color, and which gives a stereoscopic image when viewed through spectacles having filters of corresponding complementary colors.

Angle of coverage. The maximum angle subtended at a lens by light rays forming the image.

Angulator. A mechanical device used to convert the angle measured in an oblique plane to its projection on the horizontal plane.

Apparent horizon. *See* Horizon.

Attitude. The position assumed by an airplane during flight, especially the position of its longitudinal axis referred to the horizontal.

Barometer. An instrument for measuring the pressure of the atmosphere.

Aneroid barometer. A thin, hollow, corrugated metal box which changes form with changes of air pressure, thereby affording a means of measuring atmospheric pressure.

Base line. The line on the photograph connecting the indicated positions of two camera stations. When applied to the Multiplex, the line connecting the lens nodes of adjacent Multiplex projectors. Corresponds to and is a miniature representation of the air base.

Battle map. *See* Map.

Between-the-lens shutter. *See* Shutter.

Binocular vision. Simultaneous vision with both eyes.

Bridging. The extension and adjustment of photogrammetric surveys between bands of ground control.

Camera. A chamber or box upon which the images of exterior objects are projected and recorded on a sensitized surface.

Aerial camera. A camera specially designed for use in aircraft.

Copy camera. A camera specially designed for copying photographically maps and manuscripts of various sizes. Usually it is adjustable to afford a range of enlargement and reduction.

Intelligence camera. An aerial camera used to obtain intelligence information of the terrain, such as photography of enemy installations, troop dispositions, fortified areas, bomb damage, or camouflage evidence.

Orientation camera. An aerial camera used to photograph terrain at the instant of a bomb's release from an aircraft in order to locate bomber's position in relation to the target.

Precision camera. A camera capable of giving results of a definite, high order of accuracy.

Camera station. The point in space, in the air or on the ground, occupied by the camera lens at the moment of exposure.

Cantilever extension. The extension of a strip of photographs by photogrammetrical methods

from a controlled area to an area with no control. (*See* Multiplex triangulation; Radial triangulation.)

Comparator. An optical instrument, usually precise, for measuring rectangular coordinates of points on any plane surface, such as a photographic plate.

Compilation. The process of extracting map detail from aerial photographs and/or other sources, to fit a control network in the preparation of a map.

Complementary colors. Colors which, when added together, as by projection, produce white light.

Conjugate distance. For every position an object may occupy with respect to a lens, there is a corresponding position for the image. The distances to these positions are called *conjugate distances.*

Contact print. *See* Print.

Contour. An imaginary line connecting the points on a land surface that have the same elevation; also the line representing this on a map.

Contour interval. The constant difference in elevation between successive contours.

Contour map. *See* Map.

Control. A system of relatively accurate measurements to determine the distances and directions or differences in elevation between points on the earth, upon which depends a system of lesser accuracy.

Astronomic control. Control established by observation upon heavenly bodies.

Horizontal control. Control which determines horizontal positions only, as with respect to parallels and meridians or to other lines of reference.

Vertical control. Control which determines position with respect to elevations only.

Ground control. Control obtained by ground surveys as distinguished from control obtained by photogrammetric methods.

Multiplex control. Control established from other existing control by bridging or by cantilever extension with the Multiplex projectors.

Recovered control. Control previously established from other sources, which can be identified.

Starting control (photogrammetry). Control available for the absolute orientation of the first photographs along a line of flight for which control is to be extended.

Control point. Any station in a horizontal and/or vertical control system that is identified on a photograph and used for correlating the data shown on it.

Controlled mosaic. *See* Mosaic.

Coordinates. Linear or angular quantities (usually two-dimensional) which designate the position which a point occupies in a given reference plane or system.

Plane coordinates. A system of coordinates in a horizontal plane, used to describe the positions of points with respect to an arbitrary origin by means of two distances perpendicular to each other. (Linear quantities.)

Rectangular coordinates. Same as plane coordinates, sometimes called *plane rectangular coordinates.*

Grid coordinates. A plane rectangular coordinate system based upon, and mathematically adjusted to a map projection in order that geographic positions (latitudes and longitudes) readily may be transformed into plane coordinates and the computations relating to them made by the ordinary methods of plane surveying.

Copy camera. *See* Camera.

Crab. The condition existing when the sides of the vertical photographs are not parallel to the principal-point base line. (*See* Drift.)

Culture. Those features of terrain that have been constructed by man, such as roads, trails, buildings, and canals; also boundary lines and all names and legends.

Datum. A reference element, such as a line or plane, in relation to which the positions of other elements are determined.

Diapositive. Positive print on glass, used in projecting a view with a Multiplex projector.

Dip angle. The angle between the apparent horizon and the true horizon.

Direction of tilt. The direction (azimuth) of the principal plane of a photograph.

Distortion. One of the aberrations of a photographic lens which causes images to be relatively displaced from their true positions in nature. This deformation normally is symmetrical about the optical axis of the lens.

Drift. A special condition of *crab* in which the photographer has continued to make exposures

oriented to a predetermined line of flight while the airplane has drifted with the wind.

Drift sight. An aircraft instrument used to determine drift with the wind so the plane may be oriented to a prescribed course.

Elevation. Vertical distance above the datum, usually mean sea level, to a point or object on the earth's surface.

Fiducial marks. Index marks rigidly connected with the camera lens through the camera body and forming images on the negative which define the principal point of the photograph.

Flight altitude. The vertical distance above a given datum of an aircraft in flight, or during a specified portion of a flight. The datum usually is mean ground elevation.

Flight line. A line drawn on a map or chart to represent the track over which an aircraft has been flown, or the course over which it is to be flown.

Flight map. *See* Map.

Floating mark. A mark seen as occupying a position in the three-dimensional space formed by the stereoscopic fusion of a pair of photographs, and used as a reference mark in examining or measuring the stereoscopic model.

Focal length. Perpendicular distance between the image plane and the rear node of the lens when the lens is set to project light rays from infinity.

Focal plane. The plane perpendicular to the axis of the lens in which images of points in the object field of the lens are focused.

Focal plane shutter. *See* Shutter.

Focus. (1) Characteristic of a photographic lens. A lens is said to be in focus when it is so placed with respect to the image plane that best definition of the image results.

(2) To vary the lens-image distance until best definition exists.

Form lines. Lines having the same appearance as contour lines but which have been sketched from visual observation to show the shape of the terrain rather than its elevation.

Forward lap. *See* Overlap.

Grid system. (1) A systematic network of lines on a plane surface upon which coordinates are based and to which the map features are referenced.

(2) A rectangular network of lines or a *map projection.*

Grid coordinates. *See* Coordinates.

Ground control. *See* Control

Ground survey. *See* Survey.

High-oblique photograph. An oblique photograph which shows the horizon.

Horizon:

Apparent horizon. The apparent or visible junction of earth and sky as seen from any specific position. Also called *visible horizon.*

True horizon. A horizontal plane passing through a point of vision or perspective center.

Horizon trace. An imaginary line on the plane of the photograph which represents the image of the true horizon.

Horizontalization. Leveling of the spatial model, bringing it into agreement with the vertical control.

Horizontal control. *See* Control.

Horizontal control point. A control point in a horizontal control system. (*See* Control point.)

Horizontal parallax. *See* Parallax.

Intervalometer. A timing device for automatically operating the shutter of a camera at any predetermined interval.

Isocenter. The point on a photograph intersected by the bisector of the angle between the plumb line and the photograph perpendicular.

Lens distortion. *See* Distortion.

Low-oblique photograph. An oblique photograph with the entire picture below the horizon.

Manuscript map. The original drawing of a map as compiled or constructed from various data such as ground surveys and photographs.

Map. A representation on a plane surface, at an established scale, of the physical features—natural, artificial, or both—of a part or the whole of the earth's surface by means of signs and symbols, and with the means of orientation indicated.

Aeronautical map. Known as *aeronautical chart.*

Battle map. A map suitable for the tactical and technical needs of all arms. Usually published at scales 1:20,000, 1:25,000, or 1:31,680.

Contour map. A topographic map which portrays relief by means of contour lines.

Flight map. A map on which are indicated the desired lines of flight for a photographic mission.

Photomap. The reproduction of a single photograph, composite, or mosaic, complete with grid lines and marginal data.

Planimetric map. A map which presents only the horizontal positions for the features represented; distinguished from a topographic map by the omission of relief in measurable form.

Reconnaissance map. A map prepared from a reconnaissance survey. (*See* Reconnaissance.)

Strategic map. A topographic or planimetric map used for planning operations, including movements, concentration, and supply of troops. Usually of scale 1:500,000.

Tactical map. A topographic map for general field use and tactical and logistic studies by units from corps to regiment. Usually published at scale 1:50,000, 1:62,500, 1:63,360, 1:100,000, 1:125,000, or 1:126,720.

Topographic map. A map which presents the horizontal and vertical positions of the features represented; distinguished from a planimetric map by the addition of relief in measurable form.

Map plane. Any horizontal plane to which the planimetry and relief of an area are plotted or referenced.

Map projection. *See* Projection.

Marginal data. Information in the margin of maps which is of aid in filing the maps, in interpreting them, and in determining their accuracy, as well as for general information.

Mechanical-arm template. *See* Template.

Model. *See* Stereoscopic model.

Mosaic. An assembly of two or more overlapping aerial photographs. Also called *aerial mosaic.*

Controlled mosaic. A mosaic fitted to a control plot by rephotographing the component vertical photographs to compensate for scale variations resulting from tilt and for variations in flight altitude.

Uncontrolled mosaic. An assembly of two or more overlapping vertical photographs assembled only by matching photographic detail without the benefit of a framework of control points.

Strip mosaic. An assembly of a strip of vertical photographs taken in a single flight.

Mosaic index. A small-scale reproduction of a mosaic, which serves as a guide to the individual photographs and which may be used for planning mapping projects.

Multiplex. A stereoscopic plotting instrument used in preparing topographic maps by stereophotogrammetry.

Multiplex control. *See* Control.

Multiplex extension. The extension of a strip of photographs by stereophotogrammetric methods. (*See* Cantilever extension; Multiplex triangulation.)

Multiplex model. An optical projection of two overlapping images in complementary colors by means of the Multiplex projectors, which gives a stereoscopic image when viewed through spectacles having filters of corresponding complementary colors.

Multiplex projector. An instrument which forms a part of the Multiplex equipment and which projects a reduced copy of the aerial negative.

Multiplex tracing table. A piece of Multiplex equipment used for viewing the stereoscopic model, measuring the elevations in it, and compiling the detail on a map plane.

Multiplex triangulation. *See* Triangulation.

Negative. A sensitized plate or film which has been exposed in a camera and which has the lights and shades in inverse order to those of the original subject.

Nodal point, also *Node.* One of two points on the optical axis of the lens, or system of lenses, such that a ray emergent from the second point is parallel to the ray incident at the first.

Oblique photograph:

Low oblique. An aerial photograph taken with the camera axis inclined about 30° to the horizontal and at such an altitude that the image of the horizon does not appear.

High oblique. An aerial photograph taken with camera axis tilted so as to include the image of the horizon.

Optical axis. The optical axis of a lens element is a straight line which passes through the centers of curvature of the lens surfaces.

Orientation:

Relative orientation. (1) The reconstruction of the same perspective conditions between a pair of photographs which existed when the photographs were taken.

(2) The orientation of one Multiplex projector with reference to another to produce the relative relationships of the taking camera.

Absolute orientation. The fixation of scale, position, and orientation of the stereoscopic model produced by relative orientation with reference to the ground coordinates. A Multiplex model with correct scale and horizontalization is in absolute orientation.

Orthographic projection. See Projection.

Overlap. Amount by which one photograph overlaps the area covered by another, customarily expressed as a percentage.

Forward lap. The overlap between two photographs in the same flight.

Side lap. The overlap between photographs in adjacent parallel flights.

Overlapping pair. Two photographs taken at different exposure stations in such manner that a portion of one photograph shows the same terrain shown on a portion of the other photograph.

Overlay. A record on a transparent medium to be superimposed on another record.

Parallax. The apparent displacement of the position of a body with respect to a reference point or system, caused by a shift in the point of observation.

Absolute parallax. Considering a pair of truly vertical photographs, of equal principal distances, taken from equal flight altitudes; or a pair of rectified photographs; or a stereoscopic model formed by the Multiplex projectors of such photographs: the absolute parallax of a point is the algebraic difference, parallel to the base line, of the distances of the two images from their respective principal points. It is a measure to scale of the height of the image in space.

X-parallax or *Horizontal parallax.* Synonymous with *absolute parallax*, and also used in Multiplex operations to denote the component of distance between the corresponding images of a point in a stereoscopic model in a direction parallel to the vertical plane containing the base line when that model is intercepted by a horizontal plane, such as the platen of the Multiplex tracing table.

Y-parallax or *Vertical parallax.* The difference of the perpendicular distances of the two corresponding images of a point in overlapping photographs or projections of photographs from the vertical plane containing the base line.

Pass point. A point the horizontal and/or vertical position of which is determined from photographs by photogrammetric methods, and which is intended for use after the manner of a ground-control point in the orientation of other photographs.

Perspective. The two-dimensional appearance of the object with referenue to the point of observation.

Perspective center. The point of origin or termination of bundles of perspective rays. In photography, the rear node of the lens is the perspective center of the photograph, and the front node of the lens is the perspective center of the object.

Perspective grid. A network of lines drawn or superimposed on a photograph, whcih represents the perspective of a systematic network of lines on the ground or datum plane.

Perspective projection. See Projection.

Photogrammetry. The science and art of obtaining reliable méasurements from photographs.

Photograph. A general term for a positive or negative picture made by a camera on plate, film, or other medium.

Photograph perpendicular. The perpendicular from the interior perspective center—rear node of the lens—to the plane of the photograph.

Photomap. See Map.

Plane coordinates. See Coordinates.

Planimetry. Parts of a map which represent everything except relief, that is, works of man, and natural features such as woods and water.

Planimetric map. See Map.

Plotting scale. The scale at which a map is to be compiled. The scale of the Multiplex model when in absolute orientation.

Plumb point. The point on the ground vertically beneath the perspective center of the camera lens.

Positive. A photograph having the same approximate rendition of light and shade as the original subject.

Precision camera. See Camera.

Principal distance. The perpendicular distance from the interior perspective center to the plane of a particular finished negative or print. Distance from the rear node of the lens to the principal point of a photograph.

Principal line. The trace of the principal plane upon the photograph. (*See* Principal plane.)

Principal plane. The vertical plane through the internal perspective center containing the photo-

graph perpendicular of an oblique photograph, that is, any photograph which is not a truly vertical photograph.

Principal point. The foot of the perpendicular from the interior perspective center to the plane of the photograph, that is, the foot of the photograph perpendicular.

Print. A photographic copy made by projection or contact printing from a photographic negative or from a transparent drawing, as in blue printing.

Contact print. A print made with the negative or transparent drawing in contact with the sensitized surface.

Ratio print. A print the scale of which has been changed from that of the negative by photographic enlargement, reduction, or restitution.

Projection. (1) In geometry, the extension of lines or planes to intersect a given surface.

(2) The transfer of a point from one surface to a corresponding position on another surface by graphical or analytical methods.

Map projection. (1) A systematic drawing of lines on a plane surface to represent the parallels of latitude and the meridians of longitude of the earth or a section of the earth.

(2) A geometric projection on a plane surface.

Perspective projection. The projection of points by straight lines drawn through them from some given point to an intersection with the plane of projection.

Orthographic projection. A perspective projection of points by straight lines from a point of projection at an infinite distance from the plane of the drawing.

Projection distance. In the Multiplex projector, the distance from the front node of the projector lens to the plane of projection.

Radial. A line or direction from the radial center to any point on a photograph. The radial center for truly-vertical photographs is the principal point.

Radial triangulation. See Triangulation.

Ratio print. See Print.

Ray of light. The geometrical conception of a single element of light propagated in a straight line, and of infinitesimal cross section, used in tracing analytically the path of light through an optical system.

Reconnaissance. A general examination or survey of a region with reference to its main features, usually as a preliminary to a more detailed survey.

Recovered control. See Control.

Rectangular coordinates. See Coordinates.

Rectification. The process of projecting a tilted or oblique photograph to a horizontal reference plane, the angular relation between the photograph and the plane being determined from known or estimated data.

Rectified photograph. A photographic print made by projection in a rectifying printer which has been properly set for rectification.

Reduction printer. Special printer used to make diapositives from original aerial negatives for Multiplex use.

Relative orientation. See Orientation.

Relief. The variation in the height of the earth's surface. The third dimension in depth perception.

Representative fraction. (1) Ratio of distance measured on a map to the corresponding distance on the ground measured in the same unit of measurement.

(2) The scale of a map. (*See* Scale.)

Reproduction. The summation of all the processes involved in printing copies from an original drawing.

Scale. The ratio of distance measured on a map to the corresponding distance on the ground. Different from representative fraction only in that scale can be expressed in other than fractional form, that is, such as an equation with different units of measurement on each side.

Scaling. (1) Alteration of the scale in photogrammetric triangulation to bring the model into agreement with a plot of horizontal control.

(2) Fitting a stereoscopic model to a horizontal control plot. A step in *absolute orientation.*

Shutter. The mechanism of a camera which, when set in motion, permits light to reach the sensitized surface of the film or plate for a predetermined length of time.

Focal-plane shutter. A shutter located near the focal plane, consisting of a curtain with a slot which is pulled across the focal plane to make the exposure.

Between-the-lens shutter. A shutter located between the lens elements of a camera, usually consisting of thin metal leaves which

open and close, or revolve, to make the exposure.

Side lap. *See* Overlap.

Slotted template. *See* Template.

Spatial model. A stereoscopic model. (*See* Stereoscopic model.)

Stereoscopy. The science and art which deal with stereoscopic effects and the methods by which they are produced.

Stereoscopic fusion. That mental process which combines two perspective images of an object on the retinas of the eyes to give a mental impression of a three-dimensional model.

Stereoscopic image or *Stereoscopic model.* That mental impression of a three-dimensional model which results from stereoscopic fusion of a stereoscopic pair.

Stereoscopic pair. Two photographs of the same area taken from different camera stations in such a manner as to afford stereoscopic vision. Also called a *stereogram.*

Stereoscopic vision. That particular application of binocular vision which enables the observer to view an object, or two different perspectives of an object—as two photographs of the same image taken from different camera stations—and to obtain therefrom the mental impression of a three-dimensional model.

Stereogram. *See* Stereoscopic pair.

Stereoscope. An optical instrument for assisting the observer in obtaining stereoscopic vision from two properly prepared photographs.

Strategic map. *See* Map.

Survey. The act or operation of making measurements for determining the relative positions of points on or beneath the earth's surface.

Aerial survey. (1) A survey utilizing aerial photographs as part of the surveying operations.

(2) The taking of aerial photographs for surveying purposes.

Ground survey. A survey made by ground methods as distinguished from an *aerial survey.* A ground survey may or may not include the use of ground photographs, but does not include the use of aerial photographs. If ground photographs are utilized, it is a photogrammetric (ground) survey.

Tactical map. *See* Map.

Template. A substitute for a photograph used in radial triangulation, on which is recorded the radial center and the radial lines taken from the photograph.

Slotted template. A mechanical template on which the radials are represented by slots cut in a sheet of cardboard, metal, or other material.

Mechanical-arm template or *Slotted-arm template.* A template which is formed by attaching slotted steel arms, which represent the radials, to a center core.

Terrain. An area of ground considered as to its extent and topography.

Tilt. The angle between the photograph perpendicular and a vertical through the air station.

Tip and tilt. In practical photogrammetry, the X and Y components of absolute tilt are referred to as tilt and tip, respectively, that is, *tip* is the rotation of a photograph about the Y-axis or the axis perpendicular to the line of flight, and *tilt* is that about the X-axis or the axis parallel to the line of flight.

Topography. The features of the actual surface of the earth considered collectively as to form.

Topographic map. *See* Map.

Traverse. A method of surveying whereby the lengths and directions of lines connecting a series of stations are measured.

Triangulation:

Aerial triangulation. The determination of relative or absolute positions of different points on the earth's surface by utilizing aerial photography.

Radial triangulation. A photogrammetric method of aerial triangulation, either analytic or graphic, utilizing overlapping vertical, nearly vertical, or oblique aerial photographs for the location of points, imaged on the photographs, in their correct relative position to one another.

Multiplex triangulation. A stereophotogrammetric method of aerial triangulation utilizing successive stereoscopic images from overlapping aerial photographs in the Multiplex projectors for the location of points, imaged on the photographs, in their correct relative position to one another.

True horizon. *See* Horizon.

Uncontrolled mosaic. *See* Mosaic.

Vertical control. *See* Control.

Vertical-control point. A control point in a vertical control system. (*See* Control point.)

Vertical parallax. *See* Parallax.

Vertical photograph. An aerial photograph made with the camera axis vertical or as nearly vertical as practicable in an aircraft.

Viewfinder. An instrument which, by means of a lens, projects a view upon a ground glass. It is used in an aircraft, in connection with a stop watch, to determine the interval of time an object takes to pass between two lines ruled upon the ground glass in such spacing as to represent a certain forward lap of the photography which is being taken. Used to determine the exposure interval to be set on the intervalometer to get the required forward lap of photography being taken, and to correct for crab in that photography.

Visible horizon. See Horizon.

Wide-angle lens. A lens having an unusually large angular field. There is no definite division point between an ordinary and a wide-angle lens, but any lens with an angular field of 80° or more is considered a wide-angle lens.

APPENDIX II

LIST OF REFERENCES

1. Army Regulations

Mapping and Charting	AR 300–15

2. Field Manuals

Aerial Photography	FM 1–35
Elementary Map and Aerial Photograph Reading	FM 21–25
Advanced Map and Aerial Photograph Reading	FM 21–26
Conventional Signs, Military Symbols, and Abbreviations	FM 21–30
Military Maps	FM 30–20
Role of Aerial Photography	FM 30–21

3. Technical Manuals

Basic Photography	TM 1–219
Aerial Photography	TM 1–220
Topographic Drafting	TM 5–230
Surveying	TM 5–235
Surveying Tables	TM 5–236
Multiplex Mapping Equipment	TM 5–244
Topography and Surveying Map Reproduction	TM 5–245

4. Special Publications, U. S. Coast and Geodetic Survey

Tables for Polyconic Projections	SP 5
Formulas and Tables for the Computation of Geodetic Positions	SP 8
Field Work	SP 26
Lambert Projection Tables for the United States	SP 52
General Theory of the Lambert Conformal Projection	SP 53
General Theory of the Polyconic Projection	SP 57

4. Special Publications, U. S. Coast and Geodetic Survey—Continued

Military Grid System	SP 59
Elements of Map Projection	SP 68
Relation Between Plane Rectangular Coordinates and Geographic Positions	SP 71
First Order Triangulation	SP 120
Triangulation Computation and Adjustment	SP 138
Leveling	SP 140
Topographic Manual	SP 144
Manual of Plane Coordinate Computation	SP 193
Manual of Traverse Computation on the Lambert Grid	SP 194
Manual of Traverse Computation on Transverse Mercator Grid	SP 195
Cartography	SP 205

5. Geological Survey Bulletins

Geographic Formulas and Tables	Bulletin No. 650
Topographical Instructions	Bulletin No. 788

6. Additional Publications War Department, Office, Chief of Engineers

Instruction Manual for the Stereocomparagraph.

Grid System for Military Maps, 0° to 7° North Latitude.

Grid System for Military Maps, 7° to 28° North Latitude.

Grid System for Military Maps, 28° to 49° North Latitude.

Grid System for Military Maps, 49° to 72° North Latitude.

APPENDIX III

MULTIPLEX PLOTTING AND PHOTOGRAPH DATA

MULTIPLEX PLOTTING AND PHOTOGRAPH DATA FOR T–5, K–17 (6-inch), AND K3B (6-inch) CAMERAS, 9- BY 9-INCH NEGATIVE

Multiplex plotting scale	Contour interval		Flight alt. (in feet) for optimum projection plane	Value (in feet) of 0.1 mm at plotting scale	K–3B (6-inch), K–17 (6-inch), T–5 cameras		
	1/500 Alt.	1/1,000 Alt.			Photograph scale	Width of photograph in miles	Area of photograph in square miles
1:2,400	5. 7	2. 8	2, 840	0. 787	1:5,680	0. 81	0. 66
1:3,600	8. 5	4. 3	4, 250	1. 181	1:8,500	1. 21	1. 46
1:4,000	9. 5	4. 7	4, 730	1. 312	1:9,460	1. 34	1. 80
1:4,800	11. 3	5. 7	5, 670	1. 575	1:11,340	1. 61	2. 59
1:5,000	11. 8	5. 9	5, 910	1. 641	1:11,820	1. 68	2. 82
1:6,000	14. 2	7. 1	7, 090	1. 969	1:14,180	2. 01	4. 04
1:7,000	16. 5	8. 3	8, 270	2. 297	1:16,540	2. 35	5. 52
1:7,200	17. 0	8. 5	8, 510	2. 362	1:17,020	2. 42	5. 86
1:8,000	18. 9	9. 5	9, 450	2. 625	1:18,900	2. 68	7. 18
1:8,400	19. 8	9. 9	9, 920	2. 756	1:19,840	2. 82	7. 95
1:9,000	21. 3	10. 6	10, 630	2. 953	1:21,260	3. 02	9. 12
1:9,600	22. 7	11. 3	11, 340	3. 150	1:22,680	3. 22	10. 37
1:10,000	23. 6	11. 8	11, 810	3. 281	1:23,620	3. 36	11. 29
1:12,000	28. 4	14. 2	14, 180	3. 937	1:28,360	4. 03	16. 24
1:14,000	33. 1	16. 5	16, 540	4. 593	1:33,080	4. 70	22. 09
1:14,400	34. 0	17. 0	17, 010	4. 725	1:34,020	4. 83	23. 33
1:15,000	35. 4	17. 7	17, 720	4. 922	1:35,440	5. 03	25. 30
1:16,000	37. 8	18. 9	18, 900	5. 250	1:37,800	5. 37	28. 84
1:18,000	42. 5	21. 3	21, 260	5. 906	1:42,520	6. 04	36. 48
1:20,000	47. 2	23. 6	23, 620	6. 562	1:47,240	6. 71	45. 02
1:22,000	52. 0	26. 0	25, 990	7. 218	1:51,980	7. 38	54. 46
1:24,000	56. 7	28. 4	28, 350	7. 874	1:56,700	8. 05	64. 80
1:26,000	61. 4	30. 7	30, 710	8. 530	1:61,420	8. 72	76. 04
1:28,000	66. 1	33. 1	33, 070	9. 186	1:66,140	9. 39	88. 17
1:30,000	70. 9	35. 4	35, 430	9. 843	1:70,860	10. 06	101. 20

INDEX

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